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Nakata et al.

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(54) **RADIO COMMUNICATION CIRCUIT AND RADIO COMMUNICATION DEVICE**

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H04B 1/04 (2006.01)
H04B 1/10 (2006.01)

(52) **U.S. Cl.**
CPC ***H04B 1/10*** (2013.01); ***H04B 1/0475*** (2013.01); *H04B 2001/0416* (2013.01)

(58) **Field of Classification Search**
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USPC 455/73, 522, 69, 110, 127.1, 115.1, 455/115.2, 126, 114.3, 102, 67.11; 375/224, 296, 286, 285, 227; 330/149, 330/2
See application file for complete search history.

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Primary Examiner — Tan H Trinh
(74) *Attorney, Agent, or Firm* — Maschoff Brennan

(57) **ABSTRACT**

A radio communication circuit includes a transmitter that includes a modulator modulates a signal with a first modulation scheme and a power amplifier amplifies the signal modulated with the first modulation scheme and output the amplified signal and transmits the amplified signal, a receiver that includes a demodulator demodulates the signal output from the transmitter with a second modulation scheme that is different from the first modulation scheme, a pre-distortion compensator compensates occurred upon the amplification of the signal, of the signal input to the transmitter, based on the demodulated signal and a power controller controls supply of power to the receiver and the pre-distortion compensator and stop the supply of the power based on an average power level of the signal output from the transmitter and a peak-to-average power ratio that is a ratio of an instantaneous peak power level to the average power level.

7 Claims, 13 Drawing Sheets

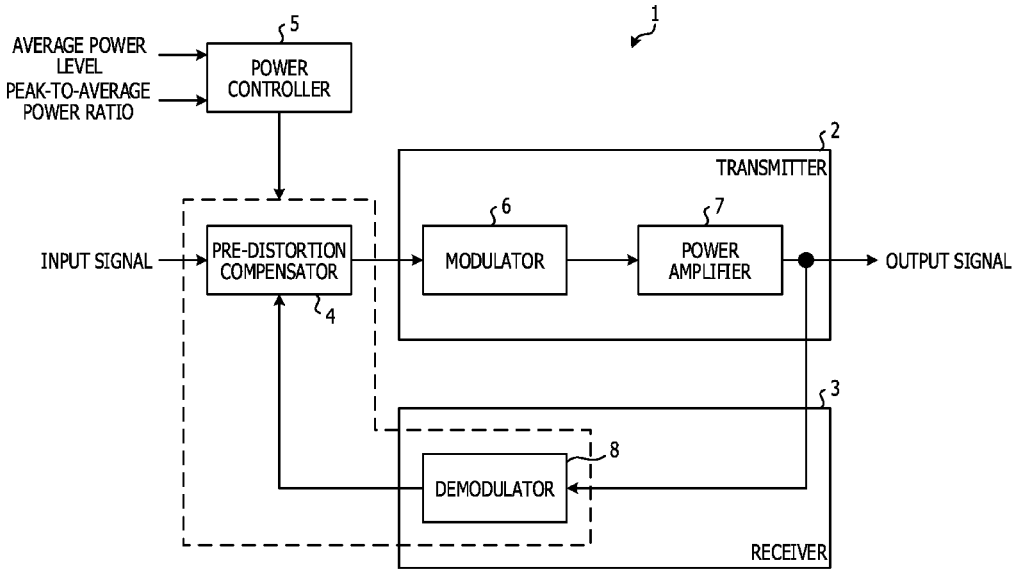

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FIG. 1

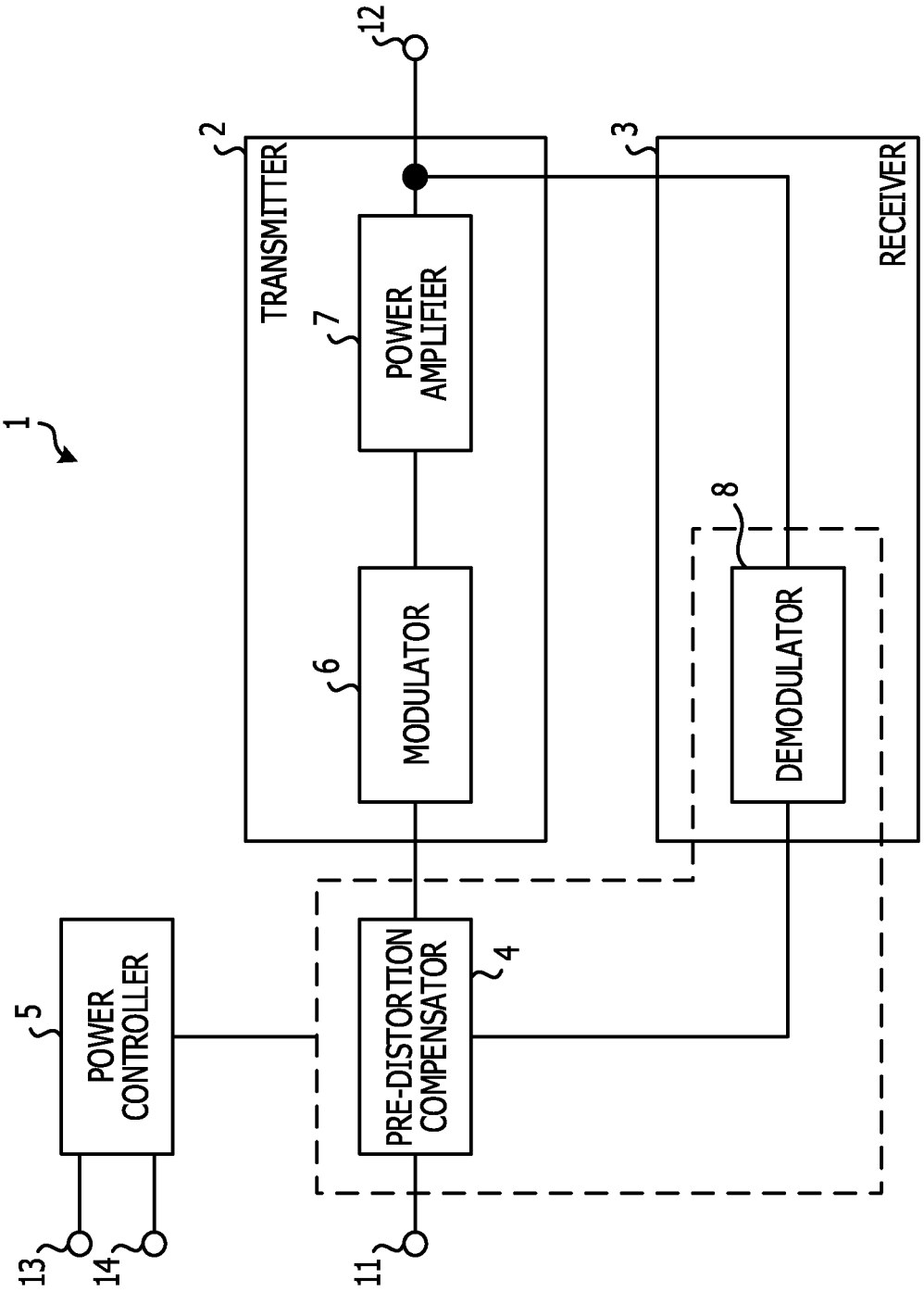

1
2
TRANSMITTER
3
RECEIVER
12
7
POWER AMPLIFIER
6
MODULATOR
8
DEMODULATOR
5
POWER CONTROLLER
PRE-DISTORTION COMPENSATOR
4
13
14
11

FIG. 2

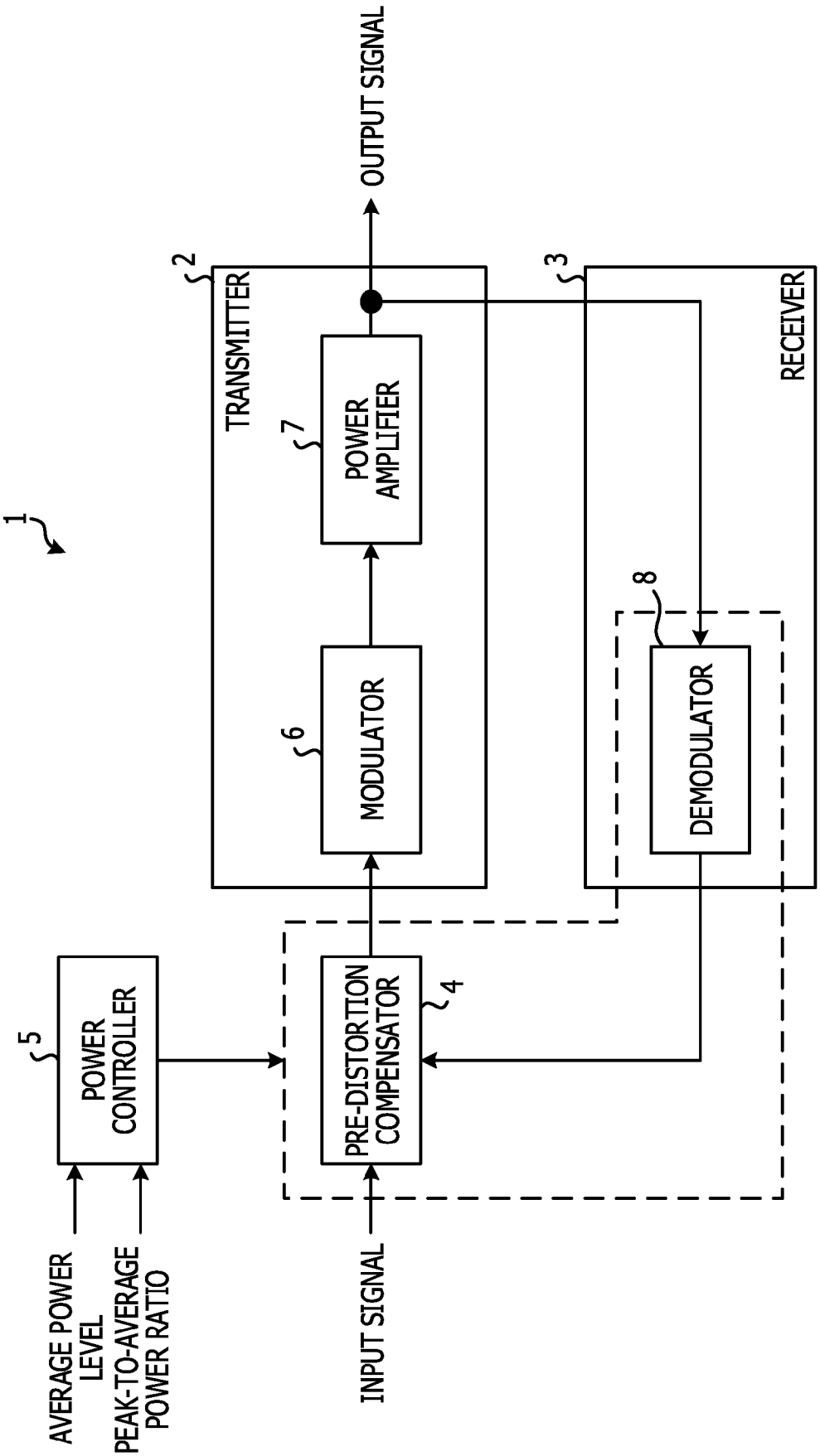

1
2
TRANSMITTER
3
RECEIVER
OUTPUT SIGNAL
7
POWER AMPLIFIER
6
MODULATOR
8
DEMODULATOR
5
POWER CONTROLLER
4
PRE-DISTORTION COMPENSATOR
AVERAGE POWER LEVEL
PEAK-TO-AVERAGE POWER RATIO
INPUT SIGNAL

FIG. 3

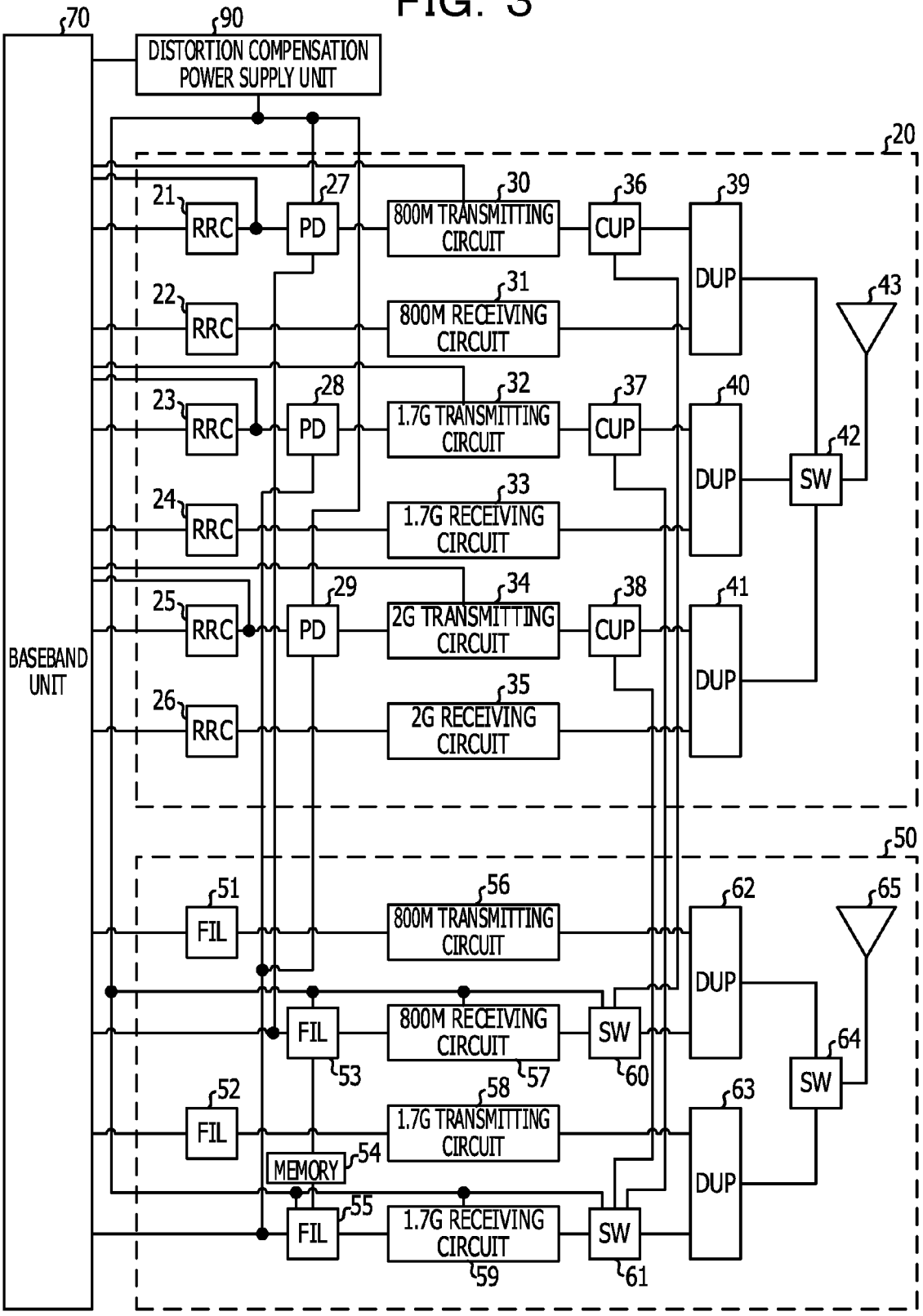

70
90
DISTORTION COMPENSATION POWER SUPPLY UNIT
20
21
RRC
27
PD
30
800M TRANSMITTING CIRCUIT
36
CUP
39
DUP
22
RRC
31
800M RECEIVING CIRCUIT
43
23
RRC
28
PD
32
1.7G TRANSMITTING CIRCUIT
37
CUP
40
DUP
42
SW
24
RRC
33
1.7G RECEIVING CIRCUIT
25
RRC
29
PD
34
2G TRANSMITTING CIRCUIT
38
CUP
41
DUP
BASEBAND UNIT
26
RRC
35
2G RECEIVING CIRCUIT
50
51
FIL
56
800M TRANSMITTING CIRCUIT
62
DUP
65
FIL
53
800M RECEIVING CIRCUIT
57
SW
60
64
SW
52
FIL
58
1.7G TRANSMITTING CIRCUIT
63
DUP
MEMORY
54
FIL
55
1.7G RECEIVING CIRCUIT
59
SW
61
DUP

FIG. 4

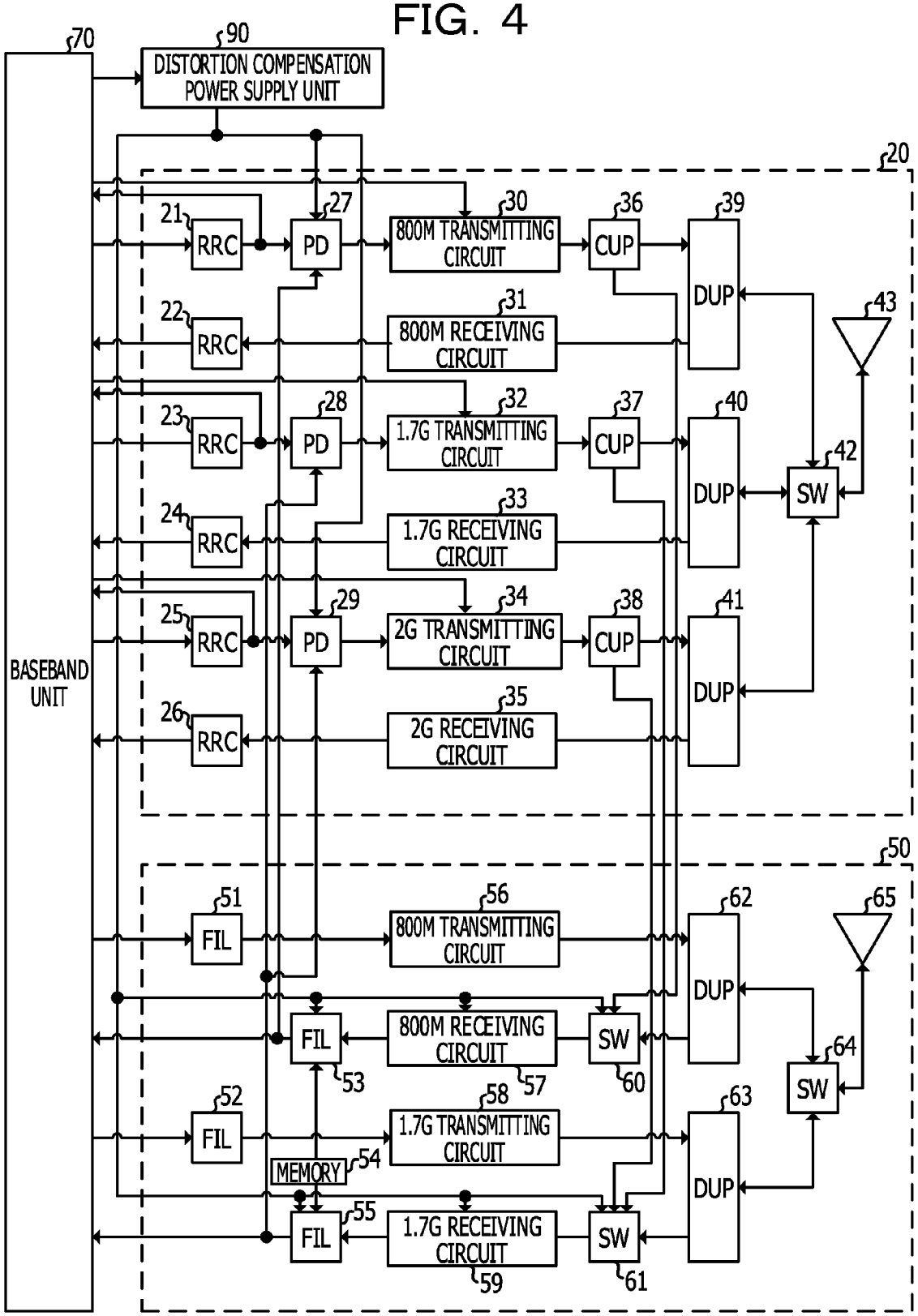

70
90
DISTORTION COMPENSATION POWER SUPPLY UNIT
20
21
RRC
27
PD
30
800M TRANSMITTING CIRCUIT
36
CUP
39
DUP
22
RRC
31
800M RECEIVING CIRCUIT
43
23
RRC
28
PD
32
1.7G TRANSMITTING CIRCUIT
37
CUP
40
DUP
42
SW
24
RRC
33
1.7G RECEIVING CIRCUIT
25
RRC
29
PD
34
2G TRANSMITTING CIRCUIT
38
CUP
41
DUP
BASEBAND UNIT
26
RRC
35
2G RECEIVING CIRCUIT
50
51
FIL
56
800M TRANSMITTING CIRCUIT
62
DUP
65
FIL
53
800M RECEIVING CIRCUIT
57
SW
60
64
SW
52
FIL
58
1.7G TRANSMITTING CIRCUIT
63
DUP
MEMORY
54
FIL
55
1.7G RECEIVING CIRCUIT
59
SW
61

FIG. 5

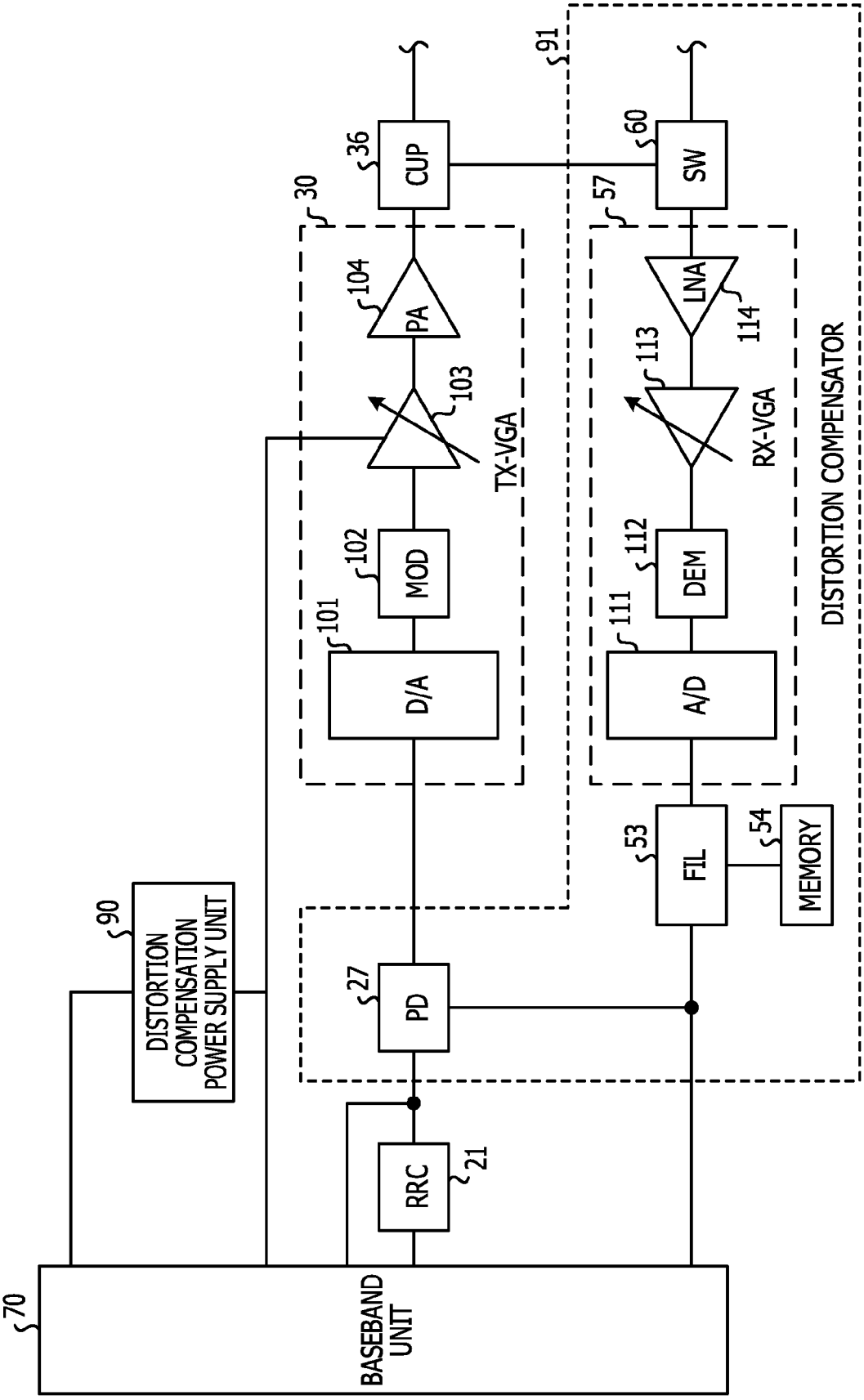

70
BASEBAND UNIT
90
DISTORTION COMPENSATION POWER SUPPLY UNIT
21
RRC
27
PD
30
101
D/A
102
MOD
103
TX-VGA
104
PA
36
CUP
91
DISTORTION COMPENSATOR
111
A/D
112
DEM
113
RX-VGA
114
LNA
57
60
SW
53
FIL
54
MEMORY

FIG. 6

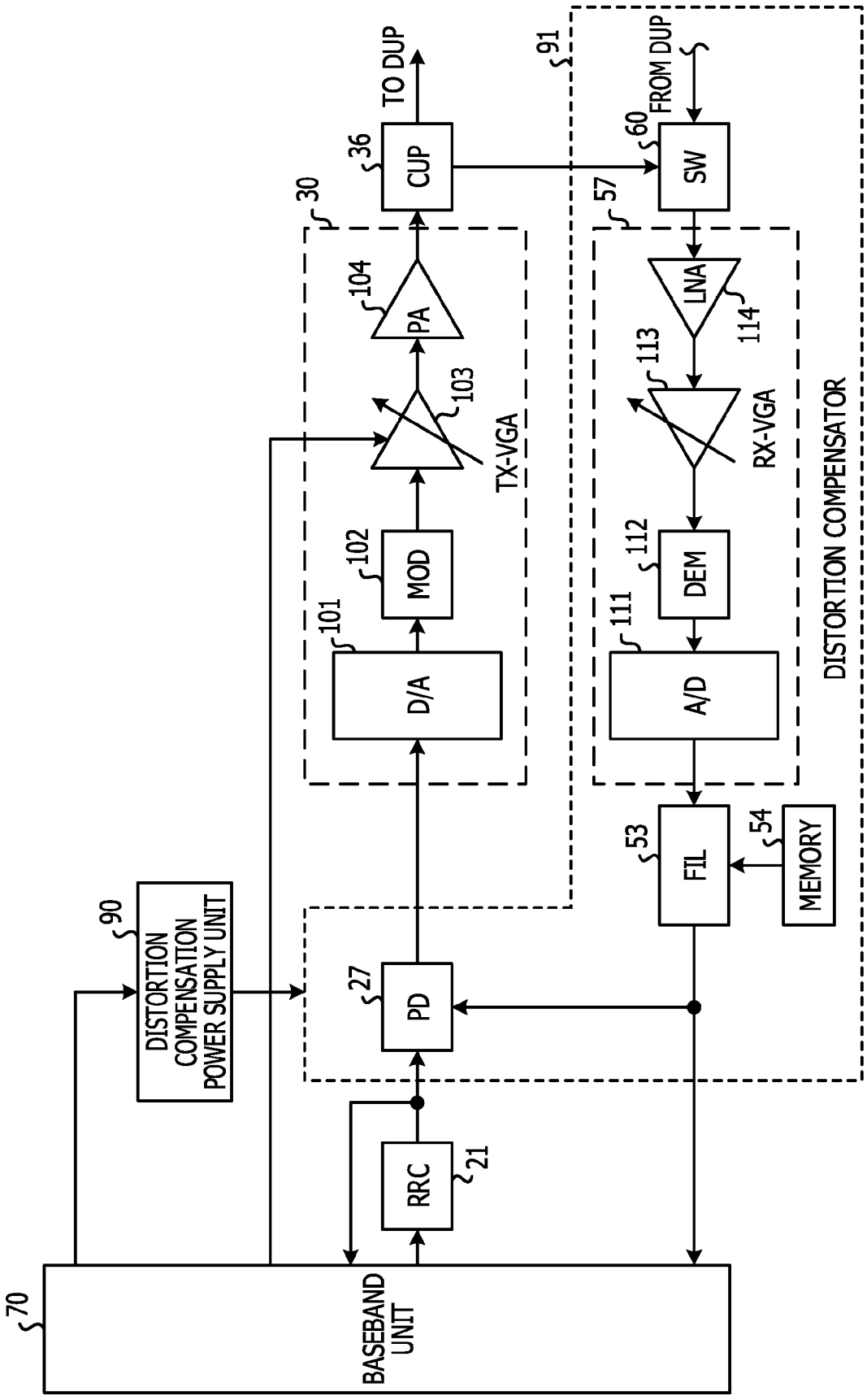

70
BASEBAND UNIT
RRC
21
PD
27
DISTORTION COMPENSATION POWER SUPPLY UNIT
90
D/A
101
MOD
102
TX-VGA
103
PA
104
CUP
36
TO DUP
30
91
DISTORTION COMPENSATOR
A/D
111
DEM
112
RX-VGA
113
LNA
114
SW
60
FROM DUP
57
FIL
53
MEMORY
54

FIG. 7

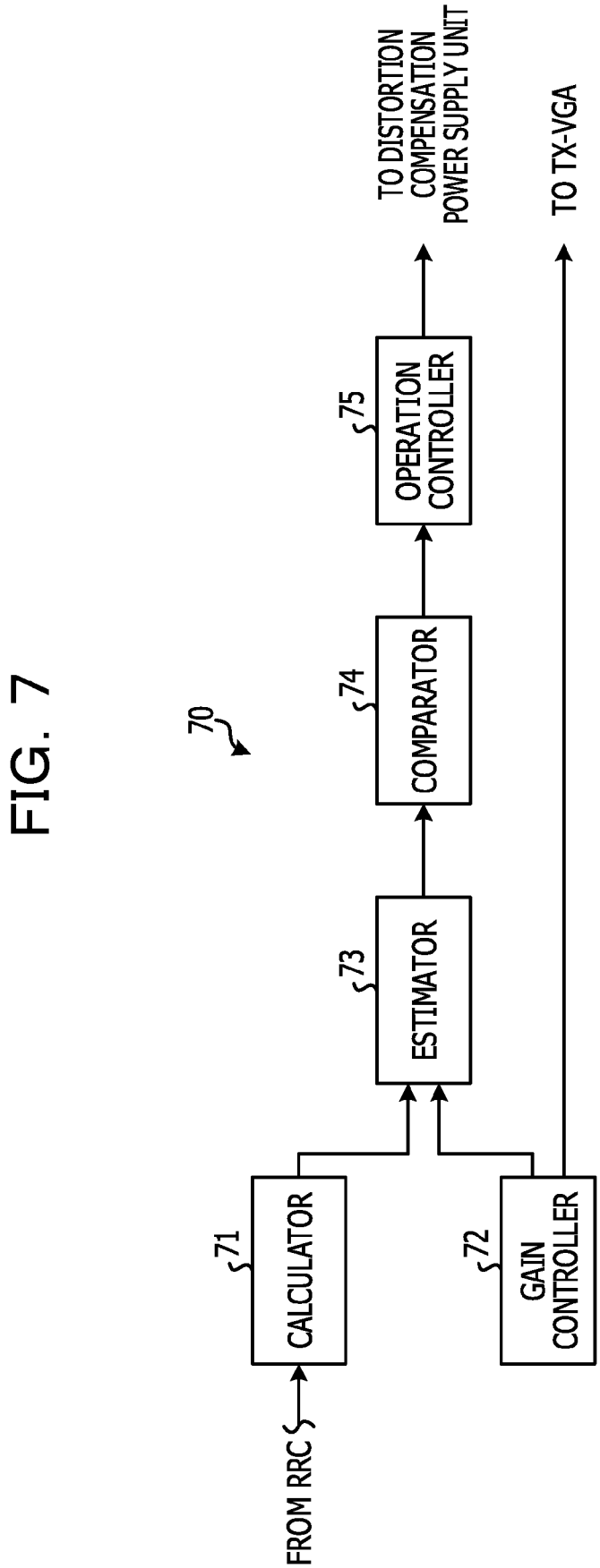

70
71
CALCULATOR
72
GAIN CONTROLLER
73
ESTIMATOR
74
COMPARATOR
75
OPERATION CONTROLLER
FROM RRC
TO TX-VGA
TO DISTORTION COMPENSATION POWER SUPPLY UNIT

FIG. 8

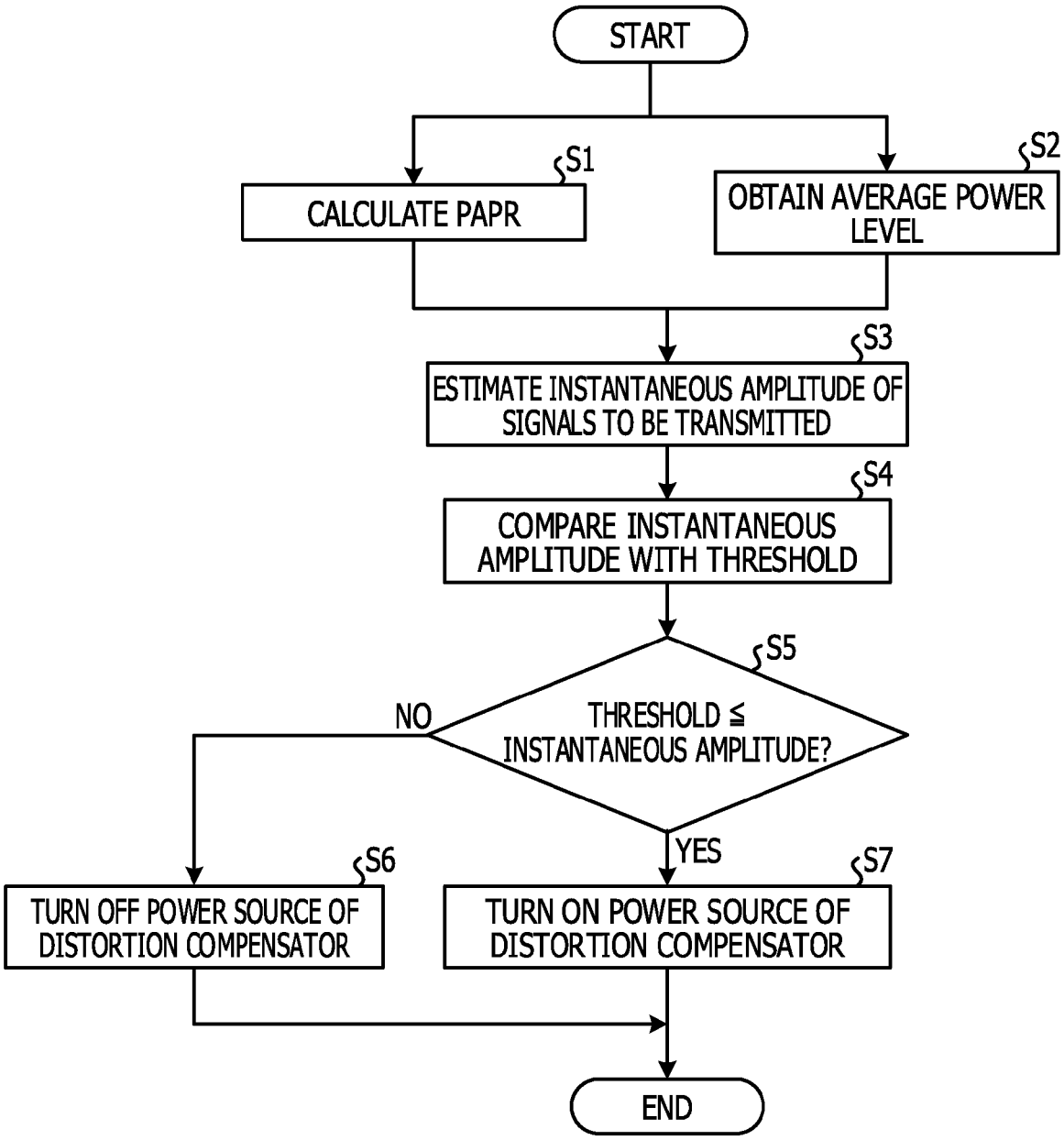

START
S1
CALCULATE PAPR
S2
OBTAIN AVERAGE POWER LEVEL
S3
ESTIMATE INSTANTANEOUS AMPLITUDE OF SIGNALS TO BE TRANSMITTED
S4
COMPARE INSTANTANEOUS AMPLITUDE WITH THRESHOLD
S5
THRESHOLD ≤ INSTANTANEOUS AMPLITUDE?
NO
YES
S6
TURN OFF POWER SOURCE OF DISTORTION COMPENSATOR
S7
TURN ON POWER SOURCE OF DISTORTION COMPENSATOR
END

FIG. 9

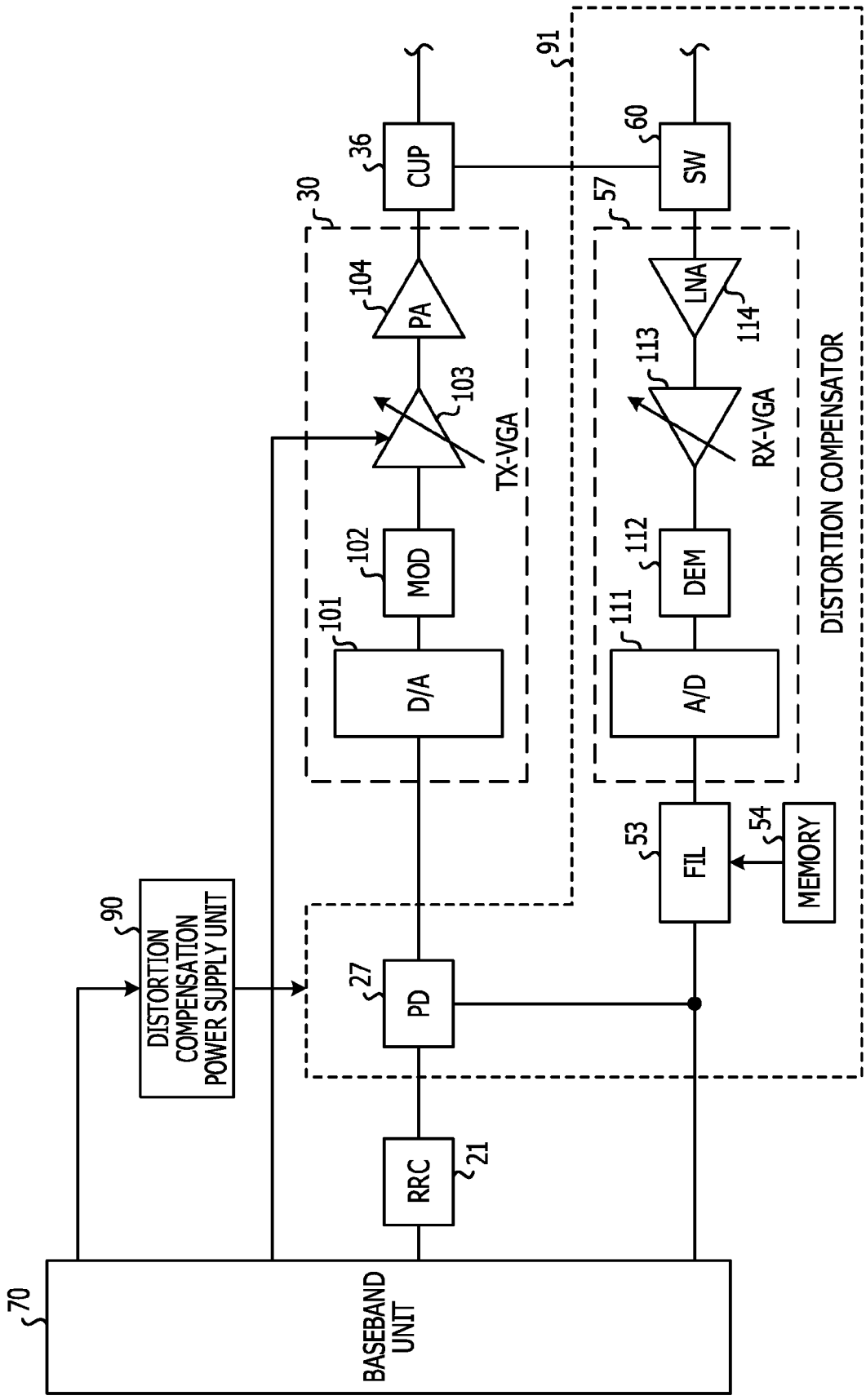

70
BASEBAND UNIT
RRC
21
90
DISTORTION COMPENSATION POWER SUPPLY UNIT
27
PD
30
101
D/A
102
MOD
103
TX-VGA
104
PA
36
CUP
91
DISTORTION COMPENSATOR
111
A/D
112
DEM
113
RX-VGA
114
LNA
57
60
SW
53
FIL
54
MEMORY

FIG. 10

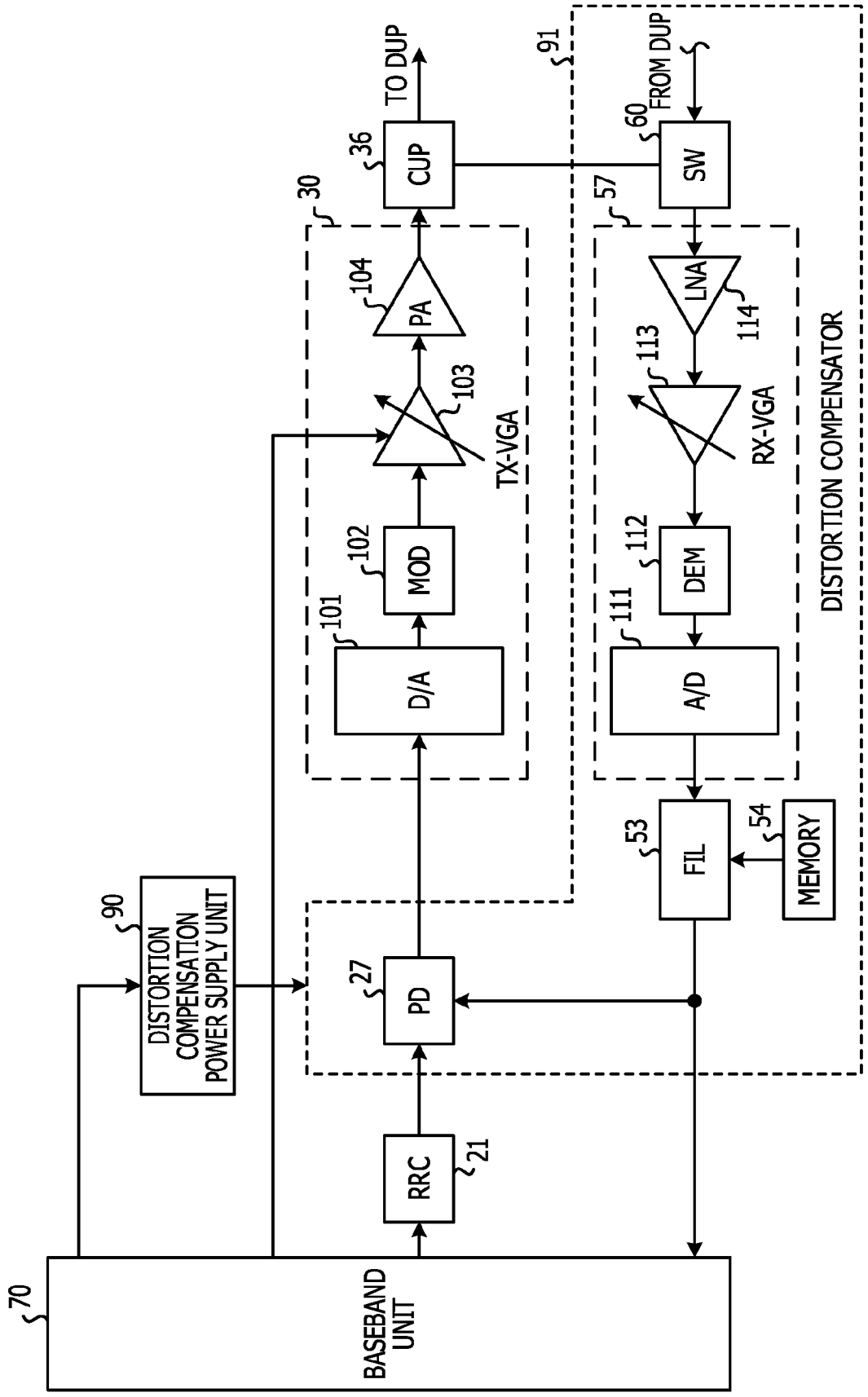

70
BASEBAND UNIT
RRC
21
DISTORTION COMPENSATION POWER SUPPLY UNIT
90
PD
27
D/A
101
MOD
102
TX-VGA
103
PA
104
30
TO DUP
CUP
36
91
FROM DUP
SW
60
57
LNA
114
RX-VGA
113
DEM
112
A/D
111
DISTORTION COMPENSATOR
FIL
53
MEMORY
54

FIG. 11

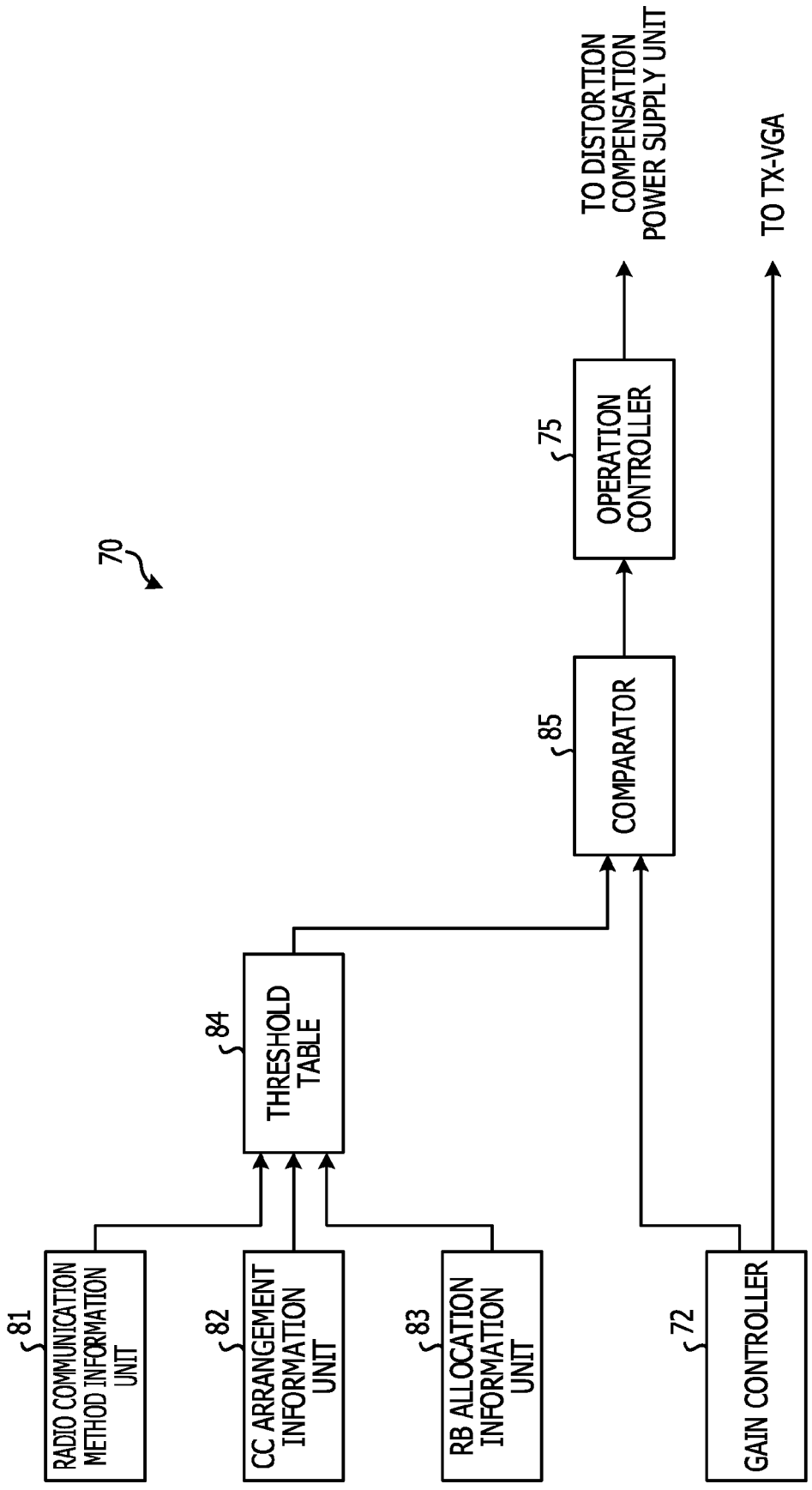
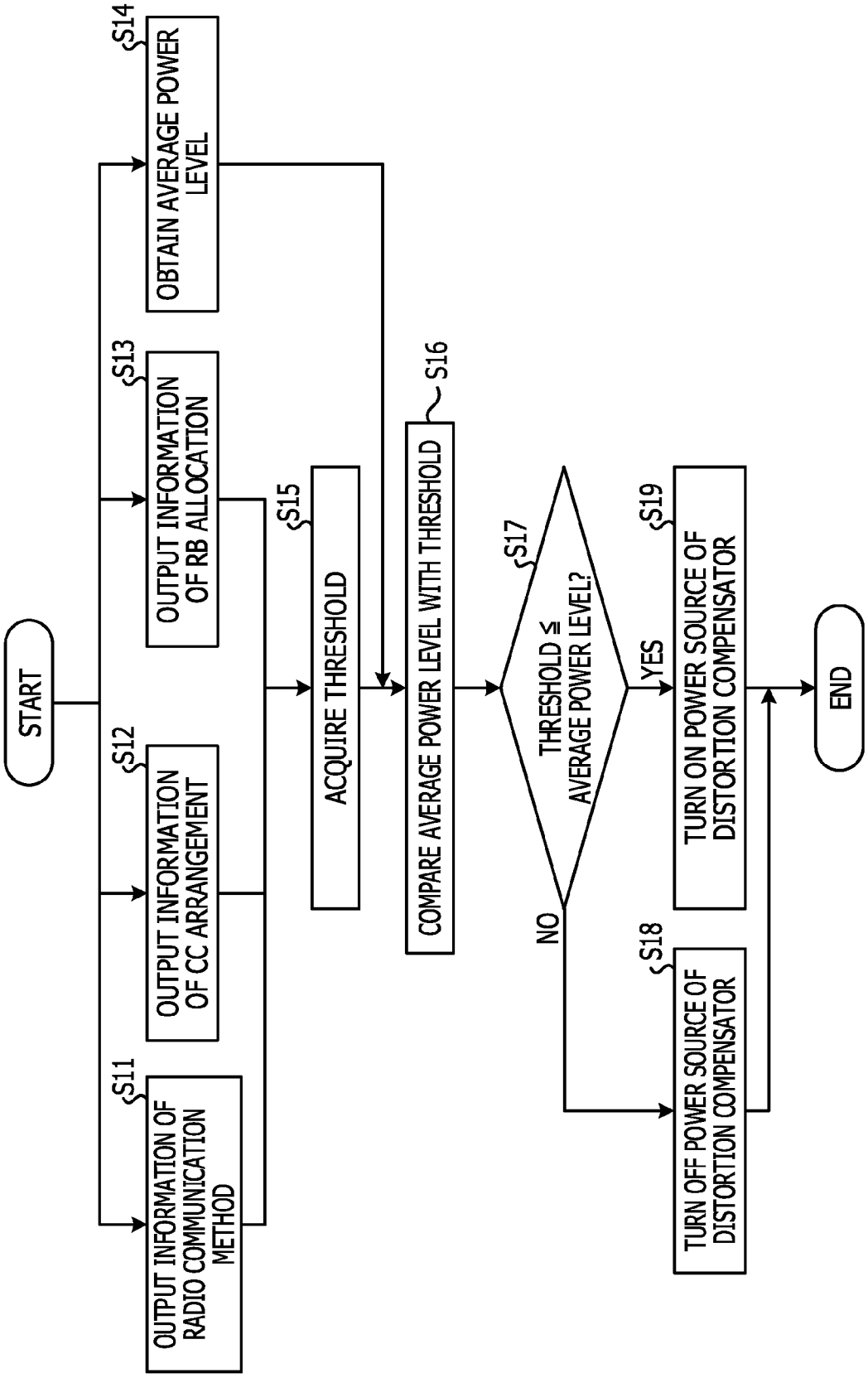

70
81
RADIO COMMUNICATION METHOD INFORMATION UNIT
82
CC ARRANGEMENT INFORMATION UNIT
83
RB ALLOCATION INFORMATION UNIT
84
THRESHOLD TABLE
85
COMPARATOR
75
OPERATION CONTROLLER
72
GAIN CONTROLLER
TO DISTORTION COMPENSATION POWER SUPPLY UNIT
TO TX-VGA

FIG. 12

84

PAPR	COMMUNICATION METHOD	THRESHOLD																								UNIT
LARGE	W-CDMA	TRANSMITTER POWER OUTPUT	+17dBm																							dBm
	LTE	RB	1	…	10	…	50	…	10	…	50	…	FULL													dBm
		TRANSMITTER POWER OUTPUT	22	…	20	…	18	…	16																	dBm
	LTE-Advanced	CC ALLOCATION	20MHz						40MHz							60MHz										dBm
		RB	1	…	10	…	50	…	FULL	1	…	10	…	50	…	FULL	1	…	10	…	50	…	FULL			
		TRANSMITTER POWER OUTPUT	21	…	19	…	17	…	14	19	…	17	…	14	…	12	17	…	15	…	13	…	11			
MEDIUM	W-CDMA	TRANSMITTER POWER OUTPUT	+17dBm																							dBm
	LTE	RB	1	…	10	…	50	…	FULL																	dBm
		TRANSMITTER POWER OUTPUT	23	…	21	…	19	…	17																	dBm
	LTE-Advanced	CC ALLOCATION	20MHz						40MHz							60MHz										dBm
		RB	1	…	10	…	50	…	FULL	1	…	10	…	50	…	FULL	1	…	10	…	50	…	FULL			
		TRANSMITTER POWER OUTPUT	22	…	20	…	18	…		20	…	18	…	16	…	14	18	…	16	…	14	…	12			
SMALL	W-CDMA	TRANSMITTER POWER OUTPUT	+17dBm																							dBm
	LTE	RB	1	…	10	…	50	…	FULL																	dBm
		TRANSMITTER POWER OUTPUT	24	…	22	…	20	…	18																	dBm
	LTE-Advanced	CC ALLOCATION	20MHz						40MHz							60MHz										dBm
		RB	1	…	10	…	50	…	FULL	1	…	10	…	50	…	FULL	1	…	10	…	50	…	FULL			
		TRANSMITTER POWER OUTPUT	23	…	21	…	19	…	17	21	…	19	…	17	…		19	…	17	…	15	…	13			

FIG. 13


START
S11
OUTPUT INFORMATION OF RADIO COMMUNICATION METHOD
S12
OUTPUT INFORMATION OF CC ARRANGEMENT
S13
OUTPUT INFORMATION OF RB ALLOCATION
S14
OBTAIN AVERAGE POWER LEVEL
S15
ACQUIRE THRESHOLD
S16
COMPARE AVERAGE POWER LEVEL WITH THRESHOLD
S17
THRESHOLD ≤ AVERAGE POWER LEVEL?
YES
NO
S18
TURN OFF POWER SOURCE OF DISTORTION COMPENSATOR
S19
TURN ON POWER SOURCE OF DISTORTION COMPENSATOR
END

RADIO COMMUNICATION CIRCUIT AND RADIO COMMUNICATION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2013-183455, filed on Sep. 4, 2013, the entire contents of which are incorporated herein by reference.

FIELD

The embodiment discussed herein is related to a radio communication circuit and a radio communication device.

BACKGROUND

Traditionally, there has been a radio communication device that causes a receiving system of a modulation scheme that is different from a signal to feed back the signal to a transmitting system so as to compensate for a distortion of the signal to be transmitted. In addition, there has been a distortion compensating circuit that changes, based on a power level, an operating point of a compensation amplifier for controlling a power level of a distortion occurred in a power amplifier. Those techniques are described in, for example, Japanese Laid-open Patent Publication Nos. 2009-55378 and 6-37551.

SUMMARY

According to an aspect of the invention, a radio communication circuit includes a transmitter that includes a modulator configured to modulate a signal with a first modulation scheme and a power amplifier configured to amplify the signal modulated with the first modulation scheme and output the signal amplified and is configured to transmit the signal amplified by the power amplifier, a receiver that includes a demodulator configured to demodulate the signal output from the transmitter with a second modulation scheme that is different from the first modulation scheme, a pre-distortion compensator configured to compensate for a distortion, occurred upon the amplification of the signal by the power amplifier, of the signal input to the transmitter, based on the signal demodulated by the demodulator, and a power controller configured to control supply of power to the receiver and the pre-distortion compensator and stop the supply of the power based on an average power level of the signal output from the transmitter and a peak-to-average power ratio that is a ratio of an instantaneous peak power level to the average power level.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram illustrating a first example of a radio communication circuit according to an embodiment;

FIG. **2** is a diagram illustrating the flow of a signal in the radio communication circuit illustrated in FIG. **1**;

FIG. **3** is a diagram illustrating an example of a radio communication device according to the embodiment;

FIG. **4** is a diagram illustrating the flows of signals in the radio communication device illustrated in FIG. **3**;

FIG. **5** is a diagram illustrating a second example of the radio communication circuit that achieves a distortion compensation function of the radio communication device illustrated in FIG. **3**;

FIG. **6** is a diagram illustrating the flows of signals in the radio communication circuit illustrated in FIG. **5**;

FIG. **7** is a diagram illustrating functional units achieved by a baseband unit included in the radio communication circuit illustrated in FIG. **5**;

FIG. **8** is a flowchart of operations to be executed by the radio communication circuit illustrated in FIGS. **5** to **7**;

FIG. **9** is a diagram illustrating a third example of the radio communication circuit that achieves the distortion compensation function of the radio communication device illustrated in FIG. **3**;

FIG. **10** is a diagram illustrating the flows of signals in the radio communication circuit illustrated in FIG. **9**;

FIG. **11** is a diagram illustrating functional units achieved by a baseband unit included in the radio communication circuit illustrated in FIG. **9**;

FIG. **12** is a diagram illustrating an example of a threshold table included in the baseband unit illustrated in FIG. **11**; and

FIG. **13** is a flowchart of operations to be executed by the radio communication circuit illustrated in FIGS. **9** to **12**.

DESCRIPTION OF EMBODIMENT

The conventional technique for compensating for a distortion causes an increase in power to be consumed, since a power source of the receiving system to be used to feed back a signal is normally turned on. In addition, although the amount of a distortion occurred in the power amplifier is affected by instantaneous peak power, the other conventional technique compensates for a distortion based on average power of signals that pass through the power amplifier. Thus, a power source of the circuit for compensating for a distortion is not turned off based on instantaneous peak power. Specifically, the power source of the circuit for compensating for a distortion is normally turned on even when a distortion is not compensated for due to the magnitude of the instantaneous peak power, and thus the amount of power to be consumed increases.

It is an object of the disclosure to provide a radio communication circuit and a radio communication device that reduce the amount of power to be consumed.

An embodiment of the radio communication circuit and the radio communication device is described in detail with reference to the accompanying drawings. In the following examples, the same constituent elements are represented by the same reference numerals, and a duplicated description is omitted.

First Example of Radio Communication Circuit

FIG. **1** is a diagram illustrating a first example of the radio communication circuit according to the embodiment. FIG. **2** is a diagram illustrating the flow of a signal in the radio communication circuit illustrated in FIG. **1**. As illustrated in FIGS. **1** and **2**, the radio communication circuit **1** includes a transmitter **2**, a receiver **3**, a pre-distortion compensator **4**, and a power controller **5**. The transmitter **2** includes a modulator **6** and a power amplifier **7** and outputs a signal amplified by the power amplifier **7**. The receiver **3** includes a demodulator **8** and receives the signal output from the transmitter **2**.

A first input terminal of the pre-distortion compensator **4** is connected to a signal input terminal **11** of the radio communication circuit **1**. A second input terminal of the pre-distor-

tion compensator **4** is connected to an output terminal of the demodulator **8**. An input terminal of the modulator **6** is connected to an output terminal of the pre-distortion compensator **4**. An input terminal of the power amplifier **7** is connected to an output terminal of the modulator **6**.

An input terminal of the demodulator **8** is connected to an output terminal of the power amplifier **7**. A signal output terminal **12** of the radio communication circuit **1** is connected to the output terminal of the power amplifier **7**. A first input terminal of the power controller **5** is connected to an average power level input terminal **13**. A second input terminal of the power controller **5** is connected to a peak-to-average power ratio input terminal **14**. An output terminal of the power controller **5** is connected to the pre-distortion compensator **4** and the demodulator **8**.

The transmitter **2**, the modulator **6**, the power amplifier **7**, the receiver **3**, the demodulator **8**, the pre-distortion compensator **4**, and the power controller **5** may be achieved by hardware. Alternatively, the power controller **5** may be achieved by causing a processor to execute software.

A signal to be transmitted is input to the signal input terminal **11** of the radio communication circuit **1** from an upstream-side signal processor (not illustrated), for example. The signal to be transmitted is input to the pre-distortion compensator **4**. The signal to be transmitted may be a baseband signal, for example.

The modulator **6** uses a first modulation scheme to modulate the signal output from the pre-distortion compensator **4** and outputs the modulated high-frequency signal. The high-frequency signal output from the modulator **6** is input to the power amplifier **7**.

The power amplifier **7** amplifies the signal output from the modulator **6** and outputs the signal amplified. The signal output from the power amplifier **7** is emitted into air from an antenna (not illustrated) through the signal output terminal **12** of the radio communication circuit **1**, for example. In addition, the signal output from the power amplifier **7** is input to the demodulator **8**.

The demodulator **8** uses a second modulation scheme to demodulate the high-frequency signal output from the power amplifier **7** and outputs the signal demodulated. The second modulation scheme is different from the first modulation scheme. The signal output from the demodulator **8** is input to the pre-distortion compensator **4**. The signal demodulated by the demodulator **8** may be a baseband signal, for example.

The first modulation scheme may be Wideband Code Division Multiple Access (W-CDMA), CDMA2000, Long Term Evolution (LTE), or LTE-Advanced, for example. The second modulation scheme may be Global System for Mobile Communications (GSM) (registered trademark), for example. The first and second modulation schemes may be modulation schemes other than the aforementioned modulation schemes. A combination of the first and second modulation schemes may be a combination of modulation schemes other than the aforementioned modulation schemes.

The pre-distortion compensator **4** compensates for, based on the signal output from the demodulator **8**, a distortion, occurred upon the amplification of the signal by the power amplifier **7**, of the signal input from the signal input terminal **11** of the radio communication circuit **1** and to be transmitted. For example, the pre-distortion compensator **4** may compensate for the distortion by extracting, as a distorted component, the difference between the signal to be transmitted and the signal output from the demodulator **8** and adding the distorted component to the signal to be transmitted so as to cause the distorted component to have the same amplitude as the signal to be transmitted and cause the phase of the distorted component to be opposite to the phase of the signal to be transmitted.

Information that represents an average power level is input to the average power level input terminal **13**. The average power level represents the average power level of the signal output from the transmitter **2**. Information that represents a peak-to-average power ratio is input to the peak-to-average power ratio input terminal **14**. The peak-to-average power ratio represents the ratio of an instantaneous peak power level to the average power level. Thus, the information that represents the average power level and the information that represents the peak-to-average power ratio are input to the power controller **5**. The power controller **5** is configured to control supply of power to the receiver **3** and the pre-distortion compensator **4** based on the average power level and the peak-to-average power ratio and to stop the supply of the power based on the average power level and the peak-to-average power ratio. The power controller **5** may have the information representing the average power level and the information representing the peak-to-average power ratio, instead of the fact that the information that represents the average power level and the information that represents the peak-to-average power ratio are input to the power controller **5**.

When the power is supplied to the receiver **3** and the pre-distortion compensator **4** by the power controller **5**, the demodulator **8** and the pre-distortion compensator **4** operate. Thus, the signal output from the power amplifier **7** is demodulated by the demodulator **8**. Then, the pre-distortion compensator **4** uses the signal demodulated by the demodulator **8** to compensate for the distortion of the signal to be transmitted.

When the supply of the power to the receiver **3** and the pre-distortion compensator **4** is stopped by the power controller **5**, the demodulator **8** and the pre-distortion compensator **4** stop operating. In this case, the pre-distortion compensator **4** does not compensate for the distortion of the signal to be transmitted and outputs the input signal to be transmitted without changing the signal.

In the radio communication circuit **1** illustrated in FIG. **1**, the supply of the power to the receiver **3** and the pre-distortion compensator **4** is controlled and stopped based on not only the average power level but also the peak-to-average power ratio. If the average power level is high, the peak-to-average power ratio is low, and thus the distortion is not to be compensated for by the pre-distortion compensator **4**, operations of the receiver **3** and the pre-distortion compensator **4** may be stopped. Thus, the amount of power to be consumed may be reduced, compared with a case where if the average power level is high, power is supplied to the receiver **3** and the pre-distortion compensator **4** and thereby causes the receiver **3** and the pre-distortion compensator **4** to operate.

Example of Radio Communication Device

FIG. **3** is a diagram illustrating an example of the radio communication device according to the embodiment. FIG. **4** is a diagram illustrating the flows of signals in the radio communication device illustrated in FIG. **3**. As illustrated in FIGS. **3** and **4**, the radio communication device supports multiple modes and includes a radio unit **20** of a first modulation scheme and a radio unit **50** of a second modulation scheme, for example. The radio unit **20** transmits or receives a signal using the first modulation scheme, while the radio unit **50** transmits or receives a signal using the second modulation scheme. The radio communication device includes a baseband unit **70** and a distortion compensation power supply unit **90**.

Like the first example (described above) of the radio communication circuit, the first modulation scheme may be

W-CDMA, CDMA2000, LTE, or LTE-Advanced, and the second modulation scheme may be GSM, for example. The first and second modulation schemes may be modulation schemes other than the aforementioned modulation schemes. A combination of the first and second modulation schemes may be a combination of modulation schemes other than the aforementioned modulation schemes.

The radio communication device supports multiple bands. For example, the radio unit **20** of the first modulation scheme may transmit or receive signals using frequency bands of 800 MHz, 1.7 GHz, and 2 GHz, while the radio unit **50** of the second modulation scheme may transmit or receive signals using frequency bands of 800 MHz and 1.7 GHz. The radio unit **20** of the first modulation scheme and the radio unit **50** of the second modulation scheme may transmit or receive signals using other frequency bands.

In the radio unit **20** of the first modulation scheme, a pre-distortion compensator (PD) **27** that is included in a 800 MHz frequency band signal transmitting system compensates for distortions of I and Q baseband signals to be transmitted, based on signals fed back from a 800 MHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme. The I and Q baseband signals to be transmitted are output from the baseband unit **70**. Then, a Root-Raised Cosine filter (RRC) **21** filters the I and Q baseband signals so as to limit frequency bands of the I and Q baseband signals. After that, the I and Q baseband signals are input to the PD **27**. The PD **27** is an example of a pre-distortion compensator.

When the radio communication device executes radio communication by operating the 800 MHz frequency band signal transmitting system and a 800 MHz frequency band signal receiving system in the radio **20** of the first modulation scheme, the 800 MHz frequency band signal receiving system that is included in the radio unit **50** of the second modulation scheme does not execute radio communication. Thus, the 800 MHz frequency band signal receiving system that is included in the radio unit **50** of the second modulation scheme is able to operate as a feedback circuit for feeding back a signal to be transmitted from the 800 MHz frequency band signal transmitting system included in the radio **20** of the first modulation scheme.

For example, the signals output from a 800 M transmitting circuit **30** included in the radio unit **20** of the first modulation scheme are distributed to two paths by the a coupler (CUP) **36**. The 800 M transmitting circuit **30** modulates the I and Q baseband signals output from the PD **27** into signals of an 800 MHz frequency band and transmits the signals modulated. The 800 M transmitting circuit **30** is an example of a transmitter.

In one of the two paths, the signals distributed by the CUP **36** are emitted into air from an antenna **43** through a duplexer (DUP) **39** and a switch (SW) **42**. In the other path, the signals distributed by the CUP **36** pass through the SW **60**, an 800 M receiving circuit **57**, and a waveform shaping filter (FIL) **53** in the 800 MHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme and is fed back to the PD **27** included in the 800 MHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme. The 800 M receiving circuit **57** demodulates the signals of the 800 MHz frequency band into I and Q baseband signals. The 800 M receiving circuit **57** is an example of a receiver.

In a case where the 800 MHz frequency band signal transmitting system that is included in the radio unit **20** of the first modulation scheme transmits a signal, the 800 MHz frequency band signal receiving system that is included in the radio unit **50** of the second modulation scheme operates as a feedback circuit for compensating for a distortion. In this case, the distortion compensation power supply unit **90** controls supply of power to the PD **27**, the SW **60**, the 800 M receiving circuit **57**, and the waveform shaping FIL **53** and stops the supply of the power. The PD **27** is included in the 800 MHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme, while the SW **60**, the 800 M receiving circuit **57**, and the waveform shaping FIL **53** are included in the 800 MHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme.

In the radio unit **20** of the first modulation scheme, a PD **28** that is included in a 1.7 GHz frequency band signal transmitting system compensates for, based on signals fed back from a 1.7 GHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme, distortions of I and Q baseband signals to be transmitted. The I and Q baseband signals to be transmitted are output from the baseband unit **70**. An RRC **23** filters the I and Q baseband signals so as to limit frequency bands of the I and Q baseband signals. After that, the I and Q baseband signals are input to the PD **28**. The PD **28** is an example of the pre-distortion compensator.

For example, the signals output from a 1.7 G transmitting circuit **32** included in the radio unit **20** of the first modulation scheme are distributed to two paths by a CUP **37**. The 1.7 GHz signal transmitting circuit **32** modulates the I and Q baseband signals output from the PD **28** into signals of a 1.7 GHz frequency band and transmits the signals modulated. The 1.7 G transmitting circuit **32** is an example of the transmitter.

In one of the two paths, the signals distributed by the CUP **37** are emitted into air from the antenna **43** through a DUP **40** and the SW **42**. In the other path, the other signals distributed by the CUP **37** pass through an SW **61**, a 1.7 G receiving circuit **59**, and a waveform shaping FIL **55** in the 1.7 GHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme and is fed back to the PD **28** included in the 1.7 GHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme. The 1.7 G receiving circuit **59** demodulates the signals of the 1.7 GHz frequency band into I and Q baseband signals. The 1.7 G receiving circuit **59** is an example of the receiver.

In a case where the 1.7 GHz frequency band signal transmitting system that is included in the radio unit **20** of the first modulation scheme transmits a signal, the 1.7 frequency band signal receiving system that is included in the radio unit **50** of the second modulation scheme operates as a feedback circuit for compensating for a distortion. In this case, the distortion compensation power supply unit **90** controls supply of power to the PD **28**, the SW **61**, the 1.7 G receiving circuit **59**, and the waveform shaping FIL **55** and stops the supply of the power. The PD **28** is included in the 1.7 frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme, while the SW **61**, the 1.7 G receiving circuit **59**, and the waveform shaping FIL **55** are included in the 1.7 frequency band signal receiving system included in the radio unit **50** of the second modulation scheme.

In the radio unit **20** of the first modulation scheme, a PD **29** that is included in a 2 GHz frequency band signal transmitting system compensates for, based on signals fed back from the 1.7 GHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme, distortions of I and Q baseband signals to be transmitted. The I and Q baseband signals to be transmitted are output from the baseband unit **70**. An RRC **25** filters the I and Q baseband

signals so as to limit frequency bands of the I and Q baseband signals. After that, the I and Q baseband signals are input to the PD **29**. The PD **29** is an example of the pre-distortion compensator.

For example, the signals output from a 2 G transmitting circuit **34** included in the radio unit **20** of the first modulation scheme are distributed to two paths by a CUP **38**. The 2 G transmitting circuit **34** modulates the I and Q baseband signals output from the PD **29** into signals of the 2 GHz frequency band and transmits the signals modulated. The 2 G transmitting circuit **34** is an example of the transmitter.

In one of the two paths, the signals distributed by the CUP **38** are emitted into air from the antenna **43** through a DUP **41** and the SW **42**. In the other path, the signals distributed by the CUP **38** pass through the SW **61**, the 1.7 G receiving circuit **59**, and the waveform shaping FIL **55** in the 1.7 GHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme and is fed back to the PD **29** included in the 2 GHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme. Since the frequency band of the 1.7 GHz frequency band signal receiving system overlaps the frequency band of the 2 GHz frequency band signal transmitting system, the 1.7 GHz frequency band signal receiving system that is included in the radio unit **50** of the second modulation scheme may process a signal output from the radio unit **20** of the first modulation scheme and to be transmitted at the frequency of 2 GHz.

In a case where the 2 GHz frequency band signal transmitting system that is included in the radio unit **20** of the first modulation scheme transmits a signal, the 1.7 GHz frequency band signal receiving system that is included in the radio unit **50** of the second modulation scheme operates as the feedback circuit for compensating for a distortion. In this case, the distortion compensation power supply unit **90** controls supply of power to the PD **29**, the SW **61**, the 1.7 G receiving circuit **59**, and the waveform shaping FIL **55** and stops the supply of the power. The PD **29** is included in the 2 GHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme, while the SW **61**, the 1.7 G receiving circuit **59**, and the waveform shaping FIL **55** are included in the 1.7 GHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme.

The distortion compensation power supply unit **90** controls the supply of power to the PDs **27** to **29**, the SWs **60** and **61**, the 800 M receiving circuit **57**, the 1.7 G receiving circuit **59**, and the waveform shaping FILs **53** and **55** and stops the supply of the power. The control of the supply is described later. Signals involved in the control of the supply of power by the distortion compensation power supply unit **90** or signals involved in the stop of the supply of power by the distortion compensation power supply unit **90** are input to the baseband unit **70** from the RRCs **21**, **23**, and **25** included in the 800 M, 1.7 G, and 2 G signal transmitting systems of the radio unit **20** of the first modulation scheme and are described later. In addition, signals that control gains to be used for the signal amplification by the 800 M, 1.7 G, and 2 G transmitting circuits **30**, **32**, and **34** are input from the baseband unit **70** to the 800 M, 1.7 G, and 2 G transmitting circuits **30**, **32**, and **34** included in the radio unit **20** of the first modulation scheme and are described later.

When the radio communication device operates the 800 MHz frequency band signal receiving system in the radio unit **20** of the first modulation scheme and cause the 800 MHz frequency band signal receiving system to receive a radio signal, the signal received by the antenna **43** passes through the SW **42** and the DUP **39** and is demodulated by the 800 M receiving circuit **31** into I and Q baseband signals. The RRC **22** filters the I and Q baseband signals demodulated by the 800 M receiving circuit **31** so as to limit frequency bands of the I and Q baseband signals. After that, the I and Q baseband signals are input to the baseband unit **70**.

When the radio communication device operates the 1.7 GHz frequency band signal receiving system in the radio unit **20** of the first modulation scheme and cause the 1.7 GHz frequency band signal receiving system to receive a radio signal, the signal received by the antenna **43** passes through the SW **42** and the DUP **40** and is demodulated by the 1.7 G receiving circuit **33** into I and Q baseband signals. The RRC **24** filters the I and Q baseband signals demodulated by the 1.7 G receiving circuit **33** so as to limit frequency bands of the I and Q baseband signals. After that, the I and Q baseband signals are input to the baseband unit **70**.

When the radio communication device operates the 2 GHz frequency band signal receiving system in the radio unit **20** of the first modulation scheme and cause the 2 GHz frequency band signal receiving system to receive a radio signal, the signal received by the antenna **43** passes through the SW **42** and the DUP **41** and is demodulated by the 2 G receiving circuit **35** into I and Q baseband signals. The RRC **26** filters the I and Q baseband signals demodulated by the 2 G receiving circuit **35** so as to limit frequency bands of the I and Q baseband signals. After that, the I and Q baseband signals are input to the baseband unit **70**.

In a case where the radio communication device operates the 800 MHz frequency band signal transmitting system in the radio unit **50** of the second modulation scheme so as to cause the 800 MHz frequency band signal transmitting system to transmit radio signals, I and Q baseband signals output from the baseband signal **70** and to be transmitted pass through the FIL **51** and are modulated by the 800 M transmitting circuit **56**. The signals output from the 800 M transmitting circuit **56** are emitted into air from an antenna **65** through a DUP **62** and an SW **64**.

When the radio communication device operates the 800 MHz frequency band signal receiving system in the radio unit **50** of the second modulation scheme and causes the 800 MHz frequency band signal receiving system to receive a radio signal, the signal received by the antenna **65** passes through the SW **64**, the DUP **62**, and the SW **60** and is demodulated by the 800 M receiving circuit **57** into I and Q baseband signals. The I and Q baseband signals demodulated by the 800 M receiving circuit **57** pass through the waveform shaping FIL **53** and are input to the baseband unit **70**.

In a case where the radio communication device operates the 1.7 GHz frequency band signal transmitting system in the radio unit **50** of the second modulation scheme so as to cause the 1.7 GHz frequency band signal transmitting system to transmit radio signals, I and Q baseband signals output from the baseband unit **70** and to be transmitted pass through the FIL **52** and are modulated by the 1.7 G transmitting circuit **58**. The signals output from the 1.7 G transmitting circuit **58** are emitted into air from the antenna **65** through the DUP **63** and the SW **64**.

When the radio communication device operates the 1.7 GHz frequency band signal receiving system in the radio unit **50** of the second modulation scheme and causes the 1.7 GHz frequency band signal receiving system to receive a radio signal, the signal received by the antenna **65** passes through the SW **64**, the DUP **63**, and the SW **61** and is demodulated by the 1.7 G receiving circuit **59** into I and Q baseband signals. The I and Q baseband signals demodulated by the 1.7 receiving circuit **59** pass through the waveform shaping FIL **55** and

are input to the baseband unit **70**. The waveform shaping FILs **53** and **55** are connected to a memory **54**. The memory **54** is described later.

A distortion compensation function of the radio communication device illustrated in FIG. **3** is described with reference to FIGS. **5** to **13**. The example describes a case where the 800 MHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme is configured to transmit a signal and the 800 MHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme operates as the feedback circuit for compensating for a distortion in the radio communication device illustrated in FIG. **3**.

The same applies to two combinations, a combination of the 1.7 GHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme and the 1.7 GHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme and a combination of the 2 GHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme and the 1.7 GHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme. Thus, in the following description of a combination of the 800 MHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme and the 800 MHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme, reference numerals may be interpreted as corresponding reference numerals related to the two combinations, and a description of the two combinations is omitted.

Second Embodiment of Radio Communication Circuit

FIG. **5** is a diagram illustrating a second example of the radio communication circuit that achieves the distortion compensation function of the radio communication device illustrated in FIG. **3**. FIG. **6** is a diagram illustrating the flows of signals in the radio communication circuit illustrated in FIG. **5**.

As illustrated in FIGS. **5** and **6**, in the 800 MHz frequency band signal transmitting system included in the radio unit **20** of the first modulation scheme, the 800 M transmitting circuit **30** includes a digital-to-analog converter (D/A) **101** and a modulator (MOD) **102**. In addition, the 800 M transmitting circuit **30** includes a TX-variable gain amplifier (TX-VGA) **103** and a power amplifier (PA) **104**.

An input terminal of the D/A **101** is connected to an output terminal of the PD **27**. I and Q baseband signals output from the PD **27** are digital signals. The D/A **101** converts the I and Q baseband signals output from the PD **27** into analog signals.

An input terminal of the MOD **102** is connected to an output terminal of the D/A **101**. The MOD **102** modulates the signals output from the D/A **101** into signals to be transmitted at the frequency band of 800 MHz. The MOD **102** is an example of the modulator.

An input terminal of the TX-VGA **103** is connected to an output terminal of the MOD **102**. A control terminal of the TX-VGA **103** is connected to the baseband unit **70**. The TX-VGA **103** changes a gain based on a control signal output from the baseband unit **70** and amplifies the signals output from the MOD **102**, for example. Thus, power levels of the signals to be transmitted are adjusted to values requested by a base station, for example. The TX-VGA **103** is an example of a variable gain amplifier.

An input terminal of the PA **104** is connected to an output terminal of the TX-VGA **103**. The PA **104** amplifies the signals output from the TX-VGA **103**. The PA **104** is an example of a power amplifier. The signals output from the PA **104** are distributed to the two paths by the CUP **36**. The signals distributed by the CUP **36** are transmitted to the DUP **39** included in the radio unit **20** of the first modulation scheme and the SW **60** included in the radio unit **50** of the second modulation scheme.

In the radio unit **20** of the first modulation scheme, the 1.7 G transmitting circuit **32** and the 2 G transmitting circuit **34** have the same configuration as the 800 M transmitting circuit **30**.

In the 800 MHz frequency band signal receiving system included in the radio unit **50** of the second modulation scheme, the 800 M receiving circuit **57** includes a low noise amplifier (LNA) **114** and an RX-variable gain amplifier (RX-VGA) **113**. In addition, the 800 M receiving circuit **57** includes a demodulator (DEM) **112** and an analog-to-digital converter (A/D) **111**.

The SW **60** is connected to the CUP **36** included in the radio unit **20** of the first modulation scheme and the DUP **62** included in the radio unit **50** of the second modulation scheme. When the 800 MHz frequency band signal receiving system that is included in the radio unit **50** of the second modulation scheme operates as the feedback circuit for compensating for a distortion, the SW **60** transfers the signal output from the CUP **36** to the 800 M receiving circuit **57**. When the radio communication device operates the 800 MHz frequency band signal receiving system in the radio unit **50** of the second modulation scheme to cause the 800 MHz frequency band signal receiving system to receive a radio signal, the SW **60** transfers the signal output from the DUP **62** to the 800 M receiving circuit **57**.

An input terminal of the LNA **114** is connected to an output terminal of the SW **60**. The LNA **114** is an amplifier that has a low noise factor and is configured to amplify a signal output from the SW **60**.

An input terminal of the RX-VGA **113** is connected to an output terminal of the LNA **114**. The RX-VGA **113** changes a gain based on a control signal output from a reception gain controller (not illustrated) and amplifies the signal output from the LNA **114**, for example. Thus, a signal level is adjusted to be in an optimal range included in a dynamic range of signal processing of the units arranged on the downstream side of the DEM **112**.

An input terminal of the DEM **112** is connected to an output terminal of the RX-VGA **113**. The DEM **112** demodulates the 800 MHz frequency band signal output from the RX-VGA **113** into I and Q baseband signals. The DEM **112** is an example of a demodulator.

An input terminal of the A/D **111** is connected to an output terminal of the DEM **112**. The I and Q baseband signals output from the DEM **112** are analog signals. The A/D **111** converts the I and Q baseband signals output from the DEM **112** into digital signals. The signals output from the A/D **111** are transferred to the waveform shaping FIL **53**.

The memory **54** stores frequency band data of signals to be transmitted by the plurality of transmitting systems and frequency band data of signals received by the plurality of receiving systems. For example, the memory **54** stores frequency band data of signals to be transmitted at the frequency bands of 800 MHz, 1.7 GHz, and 2 GHz from the radio unit **20** of the first modulation scheme and frequency band data of signals received at the frequency bands of 800 MHz and 1.7 GHz by the antenna **65** included in the radio unit **50** of the second modulation scheme.

The memory **54** is a nonvolatile memory such as a read only memory (ROM), an electrically erasable and program-

mable ROM (EEPROM), or a flash memory. The memory **54** may be arranged outside the radio unit **50** of the second modulation scheme.

An input terminal of the waveform shaping FIL **53** is connected to an output terminal of the A/D **111**. The waveform shaping FIL **53** determines whether a signal output from the A/D **111** is a signal distributed by the CUP **36** or a signal received by the antenna **65**. Information that represents a signal to be transmitted from the radio unit **20** of the first modulation scheme or a signal received by the radio unit **50** of the second modulation scheme is provided from a controller (not illustrated) to the waveform shaping FIL **53**. The waveform shaping FIL **53** determines, based on the information provided from the controller (not illustrated), whether the signal output from the A/D **111** is the signal distributed by the CUP **36** or the signal received by the antenna **65**.

If the waveform shaping FIL **53** determines that the signal output from the A/D **111** is the signal distributed by the CUP **36**, the waveform shaping FIL **53** reads, from the memory **54**, data that does not limit a frequency band and is among frequency band data of 800 MHz frequency band signals to be transmitted from the radio unit **20** of the first modulation scheme. Then, the waveform shaping FIL **53** does not limit a frequency band of the signal output from the A/D **111** and feeds back the signal to the PD **27**.

If the waveform shaping FIL **53** determines that the signal output from the A/D **111** is the signal received by the antenna **65**, the waveform shaping FIL **53** reads, from the memory **54**, frequency band data of the radio unit **50** of the second modulation scheme, limits the frequency band of the signal output from the A/D **111**, and transfers the signal to the baseband unit **70**.

In the radio unit **50** of the second modulation scheme, the 1.7 G receiving circuit **59** has the same configuration as the 800 M receiving circuit **57**.

The distortion compensation power supply unit **90** turns on and off a power source of a distortion compensator **91** that includes the PD **27**, the waveform shaping FIL **53**, the memory **54**, the A/D **111**, the DEM **112**, the RX-VGA **113**, the LNA **114**, and the SW **60**. Specifically, if the PD **27** compensates for a distortion, the power source of the distortion compensator **91** is turned on by the distortion compensation power supply unit **90**. Thus, signals output from the PA **104** are fed back to the PD **27** through the signal receiving system included in the radio unit **50** of the second modulation scheme. On the other hand, if the PD **27** does not compensate for a distortion, the power source of the distortion compensator **91** is turned off by the distortion compensation power supply unit **90**. If the power source is in an OFF state, the PD **27** transfers signals output from the RRC **21** to the D/A **101** without executing the distortion compensation on the signals.

FIG. **7** is a diagram illustrating functional units achieved by the baseband unit included in the radio communication circuit illustrated in FIG. **5**. As illustrated in FIG. **7**, the functional units, a calculator **71**, a gain controller **72**, an estimator **73**, a comparator **74**, and an operation controller **75**, are achieved by the baseband unit **70**. The functional units **71** to **75** may be achieved by hardware or by causing a processor to execute software.

I and Q baseband signals output from the RRC **21** are input to the calculator **71**. The calculator **71** calculates a peak-to-average power ratio based on the I and Q baseband signals output from the RRC **21**. The calculator **71** may calculate the peak-to-average power ratio using a known method, for example.

The gain controller **72** outputs, to the TX-VGA **103**, a control signal that controls the gain of the TX-VGA **103**. The gain of the TX-VGA **103** is controlled by the control signal. The gain controller **72** monitors power levels of the signals to be transmitted and controls the gain of the TX-VGA **103** based on the power levels monitored. The gain controller **72** may obtain an average power level from information that controls the gain of the TX-VGA **103**.

Information that represents the peak-to-average power ratio calculated by the calculator **71**, and information that represents the average power level and is included in the gain controller **72**, are provided to the estimator **73**. The estimator **72** combines the information of the peak-to-average power ratio with the information of the average power level and estimates the instantaneous amplitude of the signals output from the PA **104**. The estimator **73** may calculate the instantaneous amplitude using a known method, for example.

The instantaneous amplitude estimated by the estimator **73** is provided to the comparator **74**. A threshold that represents a standard instantaneous amplitude is set in the comparator **74** in advance. The comparator **74** compares the instantaneous amplitude provided from the estimator **73** with the threshold. Specifically, if the instantaneous amplitude is equal to or larger than the threshold, the comparator **74** may return "true". If the instantaneous amplitude is smaller than the threshold, the comparator **74** may return "false".

The result of the comparison of the instantaneous amplitude with the threshold is provided from the comparator **74** to the operation controller **75**. The operation controller **75** outputs, to the distortion compensation power supply unit **90** based on the comparison result provided from the comparator **74**, a control signal that causes the power source of the distortion compensator **91** to be turned on or off.

Specifically, when receiving "true" from the comparator **74**, the operation controller **75** outputs, to the distortion compensation power supply unit **90**, a control signal that causes the power source of the distortion compensator **91** to be turned on. Thus, the distortion compensation power supply unit **90** controls the power source of the distortion compensator **91** and thereby turns on the power source of the distortion compensator **91**. On the other hand, when receiving "false" from the comparator **74**, the operation controller **75** outputs, to the distortion compensation power supply unit **90**, a control signal that causes the power source of the distortion compensator **91** to be turned off. Thus, the distortion compensation power supply unit **90** controls the power source of the distortion compensator **91** and thereby turns off the power source of the distortion compensator **91**.

The calculator **71**, the gain controller **72**, the estimator **73**, the comparator **74**, the operation controller **75**, and the distortion compensation power supply unit **90** are an example of a power controller. The distortion compensation power supply unit **90** may be one of functional units achieved by the baseband unit **70**.

The reception gain controller (not illustrated) that is configured to control an automatic gain control function of the 800 M receiving circuit **57** may monitor the average power level. In addition, the reception gain controller may divide the signals output from the PA **104** and monitor the average power level based on a voltage detected by diode detection. Thus, the estimator **73** may acquire information of the average power level from the reception gain controller or obtain the information of the average power level from the average power level monitored based on the voltage detected by the diode detection.

FIG. **8** is a flowchart of operations to be executed by the radio communication circuit illustrated in FIGS. **5** to **7**. As illustrated in FIG. **8**, when the radio communication circuit starts an operation of transmitting a signal, the calculator **71**

calculates the peak-to-average power ratio (PAPR) (in step S1). In addition, the gain controller **72** monitors a power level of the signal to be transmitted and obtains the average power level (in step S2). The operations of step S1 and S2 may be executed in parallel by the calculator **71** and the gain controller **72**.

Next, the estimator **73** combines information of the peak-to-average power ratio calculated in step S1 with information of the average power level obtained in step S2 and estimates the instantaneous amplitude of the signals output from the PA **104** and to be transmitted (in step S3). Then, the comparator **74** compares the instantaneous amplitude calculated in step S3 with the threshold (in step S4).

If the instantaneous amplitude is smaller than the threshold (No in step S5), the operation controller **75** outputs, to the distortion compensation power supply unit **90**, the control signal that causes the power source of the distortion compensator **91** to be turned off. Then, the distortion compensation power supply unit **90** controls the power source of the distortion compensator **91** and thereby turns off the power source of the distortion compensator **91**. Thus, the power source of the distortion compensator **91** is turned off (in step S6).

On the other hand, if the instantaneous amplitude is equal to or larger than the threshold (Yes in step S5), the operation controller **75** outputs, to the distortion compensation power supply unit **90**, the control signal that causes the power source of the distortion compensator **91** to be turned on. Then, the distortion compensation power supply unit **90** controls the power source of the distortion compensator **91** and thereby turns on the power source of the distortion compensator **91**. Thus, the power source of the distortion compensator **91** is turned on (in step S7).

During the transmission of a signal by the radio communication circuit, the radio communication circuit repeats the aforementioned steps S1 to S7. When the signal transmission is terminated, the radio communication circuit terminates a series of the operations.

The radio communication circuit illustrated in FIGS. **5** and **7** or the radio communication device illustrated in FIG. **3** uses not only the average power level but also the peak-to-average power ratio to control the supply of power to the distortion compensator **91** and stop the supply of the power. Thus, if the average power level is high and the peak-to-average power ratio is large, the radio communication circuit illustrated in FIGS. **5** to **7** or the radio communication device illustrated in FIG. **3** may compensate for a distortion by supplying power to the distortion compensator **91** and causing the distortion compensator **91** to operate. On the other hand, if the average power level is low or if the average power level is high and the peak-to-average power ratio is small, the radio communication circuit illustrated in FIGS. **5** to **7** or the radio communication device illustrated in FIG. **3** may stop the supply of power to the distortion compensator **91** and cause the distortion compensator **91** to stop operating. Thus, the amount of power to be consumed may be reduced, compared with the case where if the average power level is high, power is supplied to the distortion compensator **91** and causes the distortion compensator **91** to operate.

In addition, the radio communication circuit illustrated in FIGS. **5** and **7** calculates the peak-to-average power ratio based on the I and Q baseband signals and may thus easily obtain the peak-to-average power ratio. In addition, the radio communication circuit illustrated in FIGS. **5** and **7** controls the power source of the distortion compensator **91** based on the result of the comparison of the instantaneous amplitude of the signals to be transmitted with the threshold so as to turn on or off the power source of the distortion compensator **91** and may thus easily control the power source of the distortion compensator **91** so as to turn on or off the power source of the distortion compensator **91**. In addition, the radio communication circuit illustrated in FIGS. **5** and **7** obtains the average power level based on the information used to control the gain of the TX-VGA **103** and may thus easily obtain the average power level.

Third Example of Radio Communication Circuit

FIG. **9** is a diagram illustrating a third example of the radio communication circuit that achieves the distortion compensation function of the radio communication device illustrated in FIG. **3**. FIG. **10** is a diagram illustrating the flows of signals in the radio communication circuit illustrated in FIG. **9**.

As illustrated in FIGS. **9** and **10**, in the third example of the radio communication circuit, I and Q baseband signals output from the RRC **21** are not input to the baseband unit **70**. Other configurations in the third example of the radio communication circuit are the same as the second example of the radio communication circuit illustrated in FIGS. **5** and **6**. Thus, a duplicated description is omitted.

FIG. **11** is a diagram illustrating functional units achieved by the baseband unit included in the radio communication circuit illustrated in FIG. **9**. As illustrated in FIG. **11**, the functional units, a radio communication method information unit **81**, a CC arrangement information unit **82**, an RB allocation information unit **83**, a threshold table **84**, a gain controller **72**, a comparator **85**, and an operation controller **75** are achieved by the baseband unit **70**. The functional units **72**, **75**, and **81** to **85** may be achieved by hardware or by causing a processor to execute software.

The radio communication method information unit **81** outputs information that represents a radio communication method for a signal to be transmitted from the radio unit **20** of the first modulation scheme. For example, if the radio communication method to be used by the radio unit **20** of the first modulation scheme is W-CDMA, the radio communication method information unit **81** outputs a value that corresponds to W-CDMA.

The CC arrangement information unit **82** outputs component carrier arrangement information of the signal to be transmitted from the radio unit **20** of the first modulation scheme. In LTE-Advanced, carrier aggregation (CA) for executing communication using multiple LTE carrier signals (component carriers (CCs)) simultaneously is introduced. The component carrier arrangement information represents an arrangement of multiple carriers to be simultaneously used. The CA is described in NTT DOCOMO Technical Journal, vol. 18, No. 2, "Carrier Aggregation Achieving Increase in Bandwidth for LTE-Advanced" (http://www.nttdocomo.co.jp/corporate/technology/rd/technical_journal/bn/vol18_2/, searched on Jul. 28, 2013).

The RB allocation information unit **83** outputs information that represents an allocation of resource blocks (RBs) of the signal to be transmitted from the radio unit **20** of the first modulation scheme. For example, in a method that is called Clustered Discrete Fourier Transform Spread-Orthogonal Frequency Division Multiplexing (Clustered DFTS-OFDM), the resource blocks to be used for transmission in a single CC may be discretely allocated on a frequency axis.

The threshold table **84** stores thresholds corresponding to the radio communication methods, allocations of resource blocks, arrangements of multiple carriers to be simultaneously used, or combinations thereof. Information representing a radio communication method, information representing an allocation of a resource block, information representing an arrangement of multiple carriers to be simultaneously used, or information of a combination thereof is

provided to the threshold table **84** from the radio communication method information unit **81**, the CC arrangement information unit **82**, or the RB allocation information unit **83**. A threshold that corresponds to the information provided to the threshold table **84** is output from the threshold table **84**. FIG. **12** illustrates an example of the threshold table **84**.

FIG. **12** is a diagram illustrating the example of the threshold table included in the baseband unit **70** illustrated in FIG. **11**. In the example illustrated in FIG. **12**, the threshold table **84** stores thresholds for transmitter power output for the radio communication methods for large, medium, and small peak-to-average power ratios. In the case of LTE, the threshold table **84** stores thresholds for transmitter power output for each of allocations of RBs. In the case of LTE-Advanced, the threshold table **84** stores thresholds for transmitter power output for each of allocations of RBs for each of CCs.

The peak-to-average power ratio varies depending on a radio communication method, an allocation of a resource block, an arrangement of multiple carriers to be simultaneously used, or a combination thereof. Thus, the peak-to-average power ratio is calculated before the generation of the threshold table **84**, while the radio communication method, the allocation of the resource block, the arrangement of the multiple carriers to be simultaneously used, or the combination thereof is changed. Then, the threshold table **84** is generated based on the peak-to-average power ratio calculated.

As illustrated in the example of FIG. **12**, the thresholds may be set so as to ensure that as the peak-to-average power ratio increases, thresholds are reduced. For example, in the case of LTE, when the number of RBs to be allocated is "1", a threshold when the peak-to-average power ratio is "small" is "+24 dBm", a threshold when the peak-to-average power ratio is "medium" is "+23 dBm", and a threshold when the peak-to-average power ratio is "large" is "+22 dBm".

For example, in the case of LTE-Advanced, when a CC to be allocated is "20 MHz" and the number of RBs to be allocated is "1", a threshold when the peak-to-average power ratio is "small" is "+23 dBm", a threshold when the peak-to-average power ratio is "medium" is "+22 dBm", and a threshold when the peak-to-average power ratio is "large" is "+21 dBm". In the example illustrated in FIG. **12**, in the case of W-CDMA, a threshold is "+17 dBm" regardless of whether the peak-to-average power ratio is "large", "medium", or "small".

Values within the threshold table **84** illustrated in FIG. **12** are an example, and values within the threshold table **84** are not limited to the values illustrated in FIG. **12**. In the case of W-CDMA, the threshold may vary depending on the peak-to-average power ratio. Values of the peak-to-average power ratio are not limited to the three levels, "large", "medium", and "small" values and may be two levels, "large" and "small" values or may be four or more levels.

The gain controller **72** obtains the average power level as described in the second example of the radio communication circuit. Thus, a duplicated description is omitted.

A threshold output from the threshold table **84**, and the information stored in the gain controller **72** and representing the average power level, are provided to the comparator **85**. The comparator **85** compares the threshold output from the threshold table **84** with the average power level stored in the gain controller **72**. Specifically, if the average power level is equal to or higher than the threshold, the comparator **85** may return "true". If the average power level is lower than the threshold, the comparator **85** may return "false".

As described in the second example of the radio communication circuit, the comparator **85** may acquire the information of the average power level from the reception gain controller (not illustrated) or may obtain the information of the average power level from the average power level monitored based on the voltage detected by the diode detection.

As described in the second example of the radio communication circuit, the operation controller **75** outputs, to the distortion compensation power supply unit **90**, the control signals that cause the power source of the distortion compensator **91** to be turned on and off. Thus, a duplicated description is omitted.

The radio communication method information unit **81**, the CC arrangement information unit **82**, the RB allocation information unit **83**, the threshold table **84**, the comparator **85**, the gain controller **72**, the operation controller **75**, and the distortion compensation power supply unit **90** are an example of the power controller. The distortion compensation power supply unit **90** may be one of functional units achieved by the baseband unit **70**.

FIG. **13** is a flowchart of operations to be executed by the radio communication circuit illustrated in FIGS. **9** to **12**. As illustrated in FIG. **13**, when the radio communication circuit starts an operation of transmitting a signal, the radio communication method information unit **81** outputs information that represents a radio communication method (in step S**11**). In addition, the CC arrangement information unit **82** outputs information that represents an arrangement of multiple carriers (in step S**12**). Furthermore, the RB allocation information unit **83** outputs information that represents an allocation of a resource block (in step S**13**). Furthermore, the gain controller **72** monitors a power level of the signal to be transmitted and obtains an average power level (in step S**14**).

If the radio communication method is W-CDMA, the CC arrangement information unit **82** and the RB allocation information unit **83** may output "null". If the radio communication method is LTE, the RB allocation information unit **83** may output "null". The operations of steps S**11**, S**12**, S**13**, and S**14** may be executed in parallel by the radio communication method information unit **81**, the CC arrangement information unit **82**, the RB allocation information unit **83**, and the gain controller **72**.

Then, the comparator **85** acquires, from the threshold table **84**, a threshold that corresponds to the information output in steps S**11** to S**13** (in step S**15**). The comparator **85** compares the average power level obtained in step S**14** with the threshold acquired in step S**15** (in step S**16**).

If the average power level is lower than the threshold as a result of the comparison (No in step S**17**), the operation controller **75** outputs, to the distortion compensation power supply unit **90**, the control signal that causes the power source of the distortion compensator **91** to be turned off. Then, the distortion compensator **90** controls the power source of the distortion compensator **91** so as to turn off the power source of the distortion compensator **91**. Thus, the power source of the distortion compensator **91** is turned off (in step S**18**).

If the average power level is equal to or higher than the threshold (Yes in step S**17**), the operation controller **75** outputs, to the distortion compensation power supply unit **90**, the control signal that causes the power source of the distortion compensator **91** to be turned on. Then, the distortion compensator **90** controls the power source of the distortion compensator **91** so as to turn on the power source of the distortion compensator **91**. Thus, the power source of the distortion compensator **91** is turned on (in step S**19**).

During the transmission of a signal by the radio communication circuit, the radio communication circuit repeats the aforementioned steps S**11** to S**19**. When the signal transmission is terminated, the radio communication circuit terminates a series of the operations.

Since the radio communication circuit illustrated in FIG. **9** and described with reference to FIGS. **11** to **13** controls the supply of power to the distortion compensator **91** based on the average power level and the peak-to-average power ratio and stops the supply of the power based on the average power level and the peak-to-average power ratio, the amount of power to be consumed may be reduced.

In addition, since the radio communication circuit illustrated in FIG. **9** and described with reference to FIGS. **11** to **13** has the threshold table **84** storing the thresholds corresponding to the radio communication methods, the arrangements of the multiple carriers, and the allocations of the resource blocks, a threshold that corresponds to a radio communication method, an arrangement of multiple carriers, and an allocation of a resource block may be acquired. Thus, the peak-to-average power ratio is not calculated for each case, and power to be used in order to calculate the peak-to-average power ratio may be reduced.

In addition, the radio communication circuit illustrated in FIG. **9** and described with reference to FIGS. **11** to **13** has the threshold table **84** storing the thresholds set so as to ensure that as the peak-to-average power ratio increases, the thresholds are reduced. Thus, even in a case where as the peak-to-average power ratio increases, the average power level is reduced, the average power level is equal to or higher than the threshold. On the other hand, in a case where even if the peak-to-average power ratio is reduced, the average power level does not increase, the average power level is lower than the threshold. Specifically, if the peak-to-average power ratio is small and the average power level is high, the supply of power to the power source of the distortion compensator **91** may be stopped and the distortion compensator **91** may be stopped operating. Thus, the amount of power to be consumed may be reduced, compared with a case where if the average power level is high, power is supplied to the power source of the distortion compensator **91** and thereby causes the distortion compensator **91** to operate.

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiment of the present invention has been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A radio communication circuit comprising:

a transmitter that includes a modulator configured to modulate a signal with a first modulation scheme and a power amplifier configured to amplify the signal modulated with the first modulation scheme and output the signal amplified and is configured to transmit the signal amplified by the power amplifier;

a receiver that includes a demodulator configured to demodulate the signal output from the transmitter with a second modulation scheme that is different from the first modulation scheme;

a pre-distortion compensator configured to compensate for a distortion, occurred upon the amplification of the signal by the power amplifier, of the signal input to the transmitter, based on the signal demodulated by the demodulator; and

a power controller configured to control supply of power to the receiver and the pre-distortion compensator and stop the supply of the power based on an average power level of the signal output from the transmitter and a peak-to-average power ratio that is a ratio of an instantaneous peak power level to the average power level.

2. The radio communication circuit according to claim **1**,

wherein the power controller calculates the peak-to-average power ratio based on a baseband signal before the modulation by the modulator.

3. The radio communication circuit according to claim **1**,

wherein the power controller calculates, based on the average power level and the peak-to-average power ratio, an instantaneous amplitude of the signal output from the power amplifier,

wherein when the peak-to-average power ratio calculated is equal to or larger than a preset threshold, the power controller supplies the power, and

wherein when the peak-to-average power ratio calculated is smaller than a preset threshold, the power controller stops the supply of the power.

4. The radio communication circuit according to claim **1**,

wherein the power controller has a table storing thresholds corresponding to radio communication methods, allocations of resource blocks, arrangements of multiple carriers to be simultaneously used, or combinations thereof, and acquires a threshold from the table based on radio communication method information representing a radio communication method to be used for the signal output from the transmitter, resource block allocation information representing an allocation of a resource block, or component carrier arrangement information representing an arrangement of multiple carriers to be simultaneously used,

wherein when the average power level is equal to or higher than the threshold acquired from the table, the power controller supplies the power, and

wherein when the average power level is lower than the threshold acquired from the table, the power controller stops the supply of the power.

5. The radio communication circuit according to claim **4**,

wherein the threshold is set so as to ensure that as the peak-to-average power ratio increases, the threshold is reduced.

6. The radio communication circuit according to claim **1**,

wherein the transmitter includes a variable gain amplifier configured to amplify a power level of the signal to be output from the transmitter so as to cause the signal to have a predetermined power level, and

wherein the power controller obtains the average power level from information that controls a gain of the variable gain amplifier.

7. A radio communication device comprising

a radio communication circuit that includes:

a transmitter that includes a modulator configured to modulate a signal with a first modulation scheme and a power amplifier configured to amplify the signal modulated with the first modulation scheme and output the signal amplified and is configured to transmit the signal amplified by the power amplifier;

a receiver that includes a demodulator configured to demodulate the signal output from the transmitter with a second modulation scheme that is different from the first modulation scheme, a pre-distortion compensator configured to compensate for a distortion, occurred upon the amplification of the signal by

the power amplifier, of the signal input to the transmitter, based on the signal demodulated by the demodulator, and

a power controller configured to control supply of power to the receiver and the pre-distortion compensator and stop the supply of the power based on an average power level of the signal output from the transmitter and a peak-to-average power ratio that is a ratio of an instantaneous peak power level to the average power level; and

a power supplier that supply the power to the receiver and the pre-distortion compensator.

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